The ASA Press

The ASA Press imprint represents a collaboration between the Acoustical Society of America and Springer dedicated to encouraging the publication of important new books in acoustics. Published titles are intended to reflect the full range of research in acoustics. ASA Press books can include all types of books published by Springer and may appear in any appropriate Springer book series.

Editorial Board

James Cottingham (Chair), Coe College
Diana Deutsch, University of California, San Diego
Mark Hamilton, University of Texas at Austin
William Hartmann, Michigan State University
Philip Marston, Washington State University
Allan Pierce, Boston University
Arthur N. Popper, University of Maryland
Erica Ryherd, Georgia Tech
Andrea Megela Simmons, Brown University
Martin Siderius, Portland State University
Ning Xiang, Rensselaer Polytechnic Institute
William Yost, Arizona State University

ASA Press

Acoustical Society of America

The mission of the **Acoustical Society of America** (www.acousticalsociety.org) is to increase and diffuse the knowledge of acoustics and promote its practical applications. The ASA is recognized as the world's premier international scientific society in acoustics, and counts among its more than 7,000 members professionals in the fields of bioacoustics, engineering, architecture, speech, music, oceanography, signal processing, sound and vibration, and noise control.

Since its first meeting in 1929, The Acoustical Society of America has enjoyed a healthy growth in membership and in stature. The present membership of approximately 7,000 includes leaders in acoustics in the United States of America and other countries. The Society has attracted members from various fields related to sound including engineering, physics, oceanography, life sciences, noise and noise control, architectural acoustics; psychological and physiological acoustics; applied acoustics; music and musical instruments; speech communication; ultrasonics, radiation, and scattering; mechanical vibrations and shock; underwater sound; aeroacoustics; macrosonics; acoustical signal processing; bioacoustics; and many more topics.

To assure adequate attention to these separate fields and to new ones that may develop, the Society establishes technical committees and technical groups charged with keeping abreast of developments and needs of the membership in their specialized fields. This diversity and the opportunity it provides for interchange of knowledge and points of view has become one of the strengths of the Society.

The Society's publishing program has historically included the *Journal of the Acoustical Society of America*, the magazine *Acoustics Today* (www.acousticstoday.org), a newsletter, and various books authored by its members across the many topical areas of acoustics. In addition, ASA members are involved in the development of acoustical standards concerned with terminology, measurement procedures, and criteria for determining the effects of noise and vibration.

E.F.F. Chladni

Treatise on Acoustics

The First Comprehensive English
Translation of E.F.F. Chladni's
Traité d'Acoustique

Translated by
Robert T. Beyer

ASA Press

Springer

E.F.F. Chladni
Wittenberg, Germany
Paris, France

Translated by
Robert T. Beyer (1920–2008)
Brown University
Providence, RI, USA

ISBN 978-3-319-20360-7   ISBN 978-3-319-20361-4 (eBook)
DOI 10.1007/978-3-319-20361-4

Library of Congress Control Number: 2015945948

Springer Cham Heidelberg New York Dordrecht London
© Springer International Publishing Switzerland 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Note on the Translation

This work was translated by Robert T. Beyer, Ph.D. (1920–2008), noted acoustician, Professor of Physics at Brown University, and Gold Medal recipient of the Acoustical Society of America. Along with other projects, Dr. Beyer worked on this translation over the last 10 years of his life. As a labor of love, this project was prepared for publication by his children and grandchildren.

The original text includes eight fold-out plates of all of the figures referenced in the text. Since Chladni does not reference the figures in strict numerical order, we have followed the original, and included them at the end of the text, for reference, in 16 standard pages.

Footnotes from the original manuscript have been retained. Additional footnotes have been added to clarify the translation for the modern reader. The key for authorship of the newly added footnotes is as follows:

RTB — Robert T. Beyer, Ph.D.

MAB — Margaret Anne Beyer

CBH — Catherine Beyer Hurst

RRB — Roberta Rea Beyer

TDR — Thomas D. Rossing, Ph.D.

JPC — James P. Cottingham, Ph.D.

GB — Guillaume Bouchoux, Ph.D.

With special thanks to Margaret Beyer, who began assisting her father with this project in 2003, for spearheading this effort and organizing the manuscript, to Rick Beyer for reproducing the plates, to Roberta Beyer for assistance with the French, and to Catherine Beyer Hurst for copy editing the final manuscript. We would also like to thank the Acoustical Society of America for their support, and especially Ken Foote for his unflagging enthusiasm. And, finally, thanks are also due to Thomas Rossing, Ph.D., who applied his depth of knowledge in musical acoustics

to a thorough review of the translation; to Guillaume Bouchoux, Ph.D., a bilingual acoustician, who checked passages in the original French when needed; and to James Cottingham, Ph.D., Chair of The Acoustical Society of America Press Editorial Board, who also reviewed the text, monitored and coordinated changes suggested by the other readers, and answered numerous editorial questions. It really does take a village!

*In loving memory of our father
and grandfather.*

Catherine Beyer Hurst

Margaret Beyer

Rick Beyer

Mary Beyer Trotter

Brian Hurst

Tim Hurst

Roberta Beyer

Andy Beyer

Julie Trotter

Rachel Trotter

Faith Trotter

Contents

Translator’s Introduction: Chladni and the State of Acoustics in 1800 xvii

Author’s Preface xxvii

Preliminary Observations 1

    1. Explanation of the Words *Sound* and *Noise* 1

    2. Subjects of Acoustics 2

Part I Numerical Ratios of Vibrations

Section 1: Primary Ratios 5

    3. Grave and Acute Tones 5

    4. Explanation of the Words *Interval*, *Melody*, *Chord*, *Harmony*, etc. 5

    5. Absolute Frequency of the Vibrations of Each Tone 6

    6. Difference of Consonant and Dissonant Intervals 8

    7. Unison and the Octave 9

    8. Other Consonant Intervals 9

    9. Consonant Chords 10

    10. Dissonant Chords 11

    11. Ordinary Scale 11

    12. Intervals 12

    13. Some Other Intervals 13

    14. Diatonic, Chromatic, and Enharmonic Progressions 13

    15. Scales of Different Tones 14

    16. Scale of the Minor Mode 15

    17. Explanation of Several Words 16

    18. Progressions from One Chord to Another 16

    19. Relative Frequencies of Sounds Contained in an Octave 17

    20. Several Other Intervals Contained in the Natural Series of Numbers 18

Section 2: Altered Ratios or Temperament	19
21. The Necessity of Temperament	19
22. The 12 Real Notes	20
23. The Results of Cycles of Fifths and Fourths	20
24. Equal and Unequal Temperaments	21
25. Preference for an Equal Temperament	21
26. Calculation for Equal Temperament	22
27. Practical Application	23
28. Rules for Judging Unequal Temperament	23
Appendix to Part I	24
29. Signs for the Tones Contained in Different Octaves	24
 Part II Characteristic Vibrations of Sounding Bodies	27
 Section 1: General Remarks	29
30. Different Types of Sounding Bodies	29
31. On Noise and on the Different Timbres of Sound	30
32. General Laws of Sound Vibrations	30
33. The Vibrations Must Be Very Small	31
34. Different Directions of Vibration	31
35. Intensity of Sound	32
 Section 2: Vibrations of Strings	33
A. Transverse Vibrations	33
36. Modes of Vibration	33
37. On the Manner of Producing These Vibrations and Making Them Visible	34
38. Coexistence of Several Vibrations	34
39. On the Curve Formed by a String in Its Transverse Vibrations	35
40. Laws of These Vibrations	35
41. Authors Consulted	36
42. A Particular Case: Where the Tone from a String Divided into Two Parts Is Lower than That of the Entire String	37
B. Longitudinal Vibrations of Strings	38
43. Different Types of Longitudinal Vibrations	38
44. Manner of Producing Them	38
45. Laws of These Vibrations	38
 Section 3: Vibrations of a Stretched Membrane	41
46. Explanations	41
47. Modes of Vibration	41
 Section 4: Vibrations of the Air in a Wind Instrument	43
48. The Air Here Is the Sounding Body	43
49. A Simple Blow Is Enough to Produce Vibrations	43
50. Sound Produced by a Current of Air Through a Slit	43

51. Reinforcement of the Sound of the Air by the Resonance of a Membrane	44
52. Voices of Humans and Animals	44
53. Differences in Pipes	46
54. Reed Stops	47
55. Flue Pipes	47
56. Kinds of Pipes	48
57. Explanation of the Manner in Which Vibrations Are Made	49
58. The Difference Between Simple and Double Parts	49
59. Simplest Motion of Air in a Closed Pipe	50
60. Simplest Motion of Air in an Open Pipe	50
61. Other Motions of Air in Closed and Open Pipes	50
62. Ratios of Sounds Equal to the Natural Series of Numbers	51
63. The Shape of the Pipe Is Unimportant	51
64. Laws of Sound	52
65. Authors Consulted	53
66. Sound Produced by the Combustion of Hydrogen Gas in a Tube	53
67. Sounds of Different Kinds of Gases	54
Section 5: Vibrations of a Rod or a Straight Strip	57
A. Transverse Vibrations	57
68. Different Cases	57
69–74. Vibrations of a Rod, One or Both Ends of Which Are Fixed, Supported, or Free	58
75. Laws of These Vibrations	61
76. Authors Consulted	62
B. Longitudinal Vibrations	62
77. Explanations	62
78. Manner of Making the Experiments	63
79–81. Different Cases	63
82. Relative Frequencies of Vibrations of Different Materials	64
83. Laws of These Vibrations, Compared with Those of Transverse Vibrations	66
C. Torsional Vibrations of a Rod	66
84. Explanation of These Vibrations	66
85. Manner of Their Production	67
86. Laws	67
87. Application of These Vibrations to Those of a Plate	67
Section 6: Vibrations of a Bent Rod	69
88. Vibrations of Forks	69
89. Vibrations of Rings	70
90. Vibrations of Other Curved Rods	71

Section 7: Vibrations of Plates	73
A. General Remarks	73
91. Explanation	73
92. Manner of Performing the Experiments	73
93. Several General Attributes of These Vibrations	76
94. Direction of the Nodal Lines	77
95. Distortions of the Figures	77
96. Affinities of the Figures Among Themselves	77
97. General Laws of the Frequency of Vibrations	78
98. Several Lessons for Those Who Wish to Be Concerned with the Theory of Oscillations	78
B. Vibrations of Rectangular Plates in General	80
99. Different Cases	80
100. Vibrations of a Rectangular Plate Whose Two Ends Are Free	81
101. Vibrations of a Rectangular Plate with One End Fixed and the Other Free	82
102. Vibrations of a Rectangular Plate with Two Ends Fixed	83
C. Vibrations of a Square Plate and Some Other Kinds of Rectangular Plates	83
103. Explanation	83
104. Nodal lines in One Direction or Another and Signs for Expressing Them	83
105. Flexions of Nodal Lines	84
106. The Essential Difference When the Nodal Lines Are Curved Inward and Outward	84
107. Types of Vibrations of a Square Plate	85
108. Ratios of the Sounds	87
109. Several Other Kinds of Vibrations in Which the Plate is Not Free	90
110. Different Patterns That Are Formed When the Plate is Not Free	90
111. Symbols for Expressing the Vibrations of Rectangular Plates	91
112. Passages of One Figure to Another, When the Sound Is the Same	92
113–123. Sounds of Rectangular Plates with Different Ratios of Their Dimensions, Regarding the Length as Constant and the Width as Variable	92
124. Summary of the Research on the Vibration of Rectangular Plates	98
D. Vibrations of a Round Plate	99
125. Nodal Lines in Diametral and Circular Directions, and Symbols for Expressing Them	99
126. Vibrations in Which There Are Only Diametral Lines	99
127. Vibrations That Present a Circular Line	100
128. Vibrations in Which There Are Two or More Circular Lines	101
129. The Bending of Circular Lines	103
130. Ratio of Sounds of a Round Plate	103
131. Some Other Types of Vibrations in Which the Plate Is Not Free	105

E. Vibrations of Elliptical Plates	105
132. General Remarks	105
133. Manner of Producing Different Kinds of Vibrations	107
134. Passages of the Figures of a Round Plate to Those of an Elliptical Plate	107
135. Some Particularly Remarkable Ratios of Axes	108
136–146. Vibrations of Elliptical Plates in Different Ratios of Axes, Regarding One Axis as a Constant and the Other as a Variable	109
147. Summary of Research on Elliptical Plates	116
F. Vibrations of Hexagonal Plates	117
148. They Differ Little from Those of a Round Plate	117
149. Figures and Ratios of the Sounds	118
G. Vibrations of Semicircular Plates	119
150. The figures Are Half Those of a Round Plate	119
151. Ratios of the Sounds	119
152. Vibrations of Plates That Are a Small Part of a Round Plate	120
H. Vibrations of Triangular and Other Plates	120
153. Vibrations and Sounds of an Equilateral Triangular Plate	120
154. Compositions and Portions of Figures That Can be Produced on Several Other Plates	121
I. Remarks on Some Practical Usage of Plates	122
155. On Two Chinese Instruments	122
Section 8: Vibrations of Bells and Vessels	123
156. General Remarks	123
157. Manner of Producing Vibrations and Making Them Visible	123
158. The Fundamental Sound of a Bell	124
159. Application to a Harmonica Bell	124
160. In Irregular Bells the Sound Is Not the Same Everywhere	124
161. Other Types of Vibrations	125
162. Laws for the Absolute Frequency of Vibrations	126
163. The Vibrations of Sounding Bodies of Other Shapes Are Still Not Known	126
Section 9: On the Coexistence of Several Modes of Vibration in the Same Sounding Body	127
164. Several Vibrations Can Coexist	127
165–170. Coexistence of Several Vibrations in a Single String	127
171. Coexistence of Several Vibrations in an Organ Pipe	130
172. Coexistence of Several Vibrations in a Rod	130
173. Coexistence of Several Vibrations in a Fork or a Ring	130
174. Coexistence of Several Vibrations in a Plate	131
175. Coexistence of Several Vibrations in a Bell	131
176. Authors Consulted	131

177. Coexistence of a Grave Sound When Two or More Acute Sounds Are Produced	132
178. Beats in Poorly Tuned Instruments Are the Same as Coexistence	133
179. Authors Consulted	134

Section 10: On the Coexistence of Vibrations with Other

Sorts of Motions	135
180. These Motions Can Coexist	135
181. On a Very Common Coexistence of a Circular Motion with Vibrations	135

Part III On Transmitted Vibrations, or the Propagation of Sound

Section 1: On the Propagation of Sound Through Air

and Through Other Gaseous Fluids	139
182. General Notions of Sound Propagation	139
183. Air Is the Ordinary Conductor of Sound	139
184. Sound Propagates in all Directions from the Center	139
185. Sound Propagation Through Air Does Not Differ Essentially from the Vibrations of Air in a Wind Instrument	140
186. Air Does Not Make More or Fewer Vibrations Than the Sounding Body	140
187. Sound Waves	141
188. Propagations of Different Tones (Timbre) of Sound	141
189. Sound Is Also Propagated Along Different Curves	142
190. Several Sounds Can Be Propagated at the Same Time in the Same Mass of Air	143
191. Uniformity of Motion	143
192. Speed of Sound According to Ordinary Theory	143
193. Results of Observations	143
194. Circumstances That Affect the Speed of Sound	144
195. Ways of Explaining the Differences Between Observation and Theory	144
196. The Speed of Sound in Different Gases	145
197. Intensity of Sound Transmitted in the Air	146
198. Intensity of Sound Transmission Through Different Types of Gases	147
199. Sound Propagation Through Vapors	149
200. Distances at Which Sound Can Be Perceived	150
201. Megaphones	150
202. Ear Trumpets	153
203. Speaking Chambers	153
204. General Explanation of an Echo	154
205. Different Cases in Which an Echo Is Formed	155
206. Remarkable Examples of Echoes	157

207–210. On the Construction of Halls That Are Favorable to Sound	158
211. Works and Dissertations that Contain Research on Sound Propagated in the Air	161

Section 2: On the Propagation of Sound Through Liquids

and Solids	163
212. All Possible Materials Propagate Sound	163
213. Propagation of Sound in Water	163
214. The Resistance of Water Delays the Vibrations of a Sounding Body	164
215. The Velocity of Sound Through Liquid Matter is Unknown	164
216. The Intensity of Sound Propagated Through Water and Through Other Liquids	164
217. Solid Matter Also Propagates Sound	165
218. Direction of Motions	166
219. Velocity of Sound Through Solids	166
220. Experiments That Have Been Performed on This Subject	167
221. Intensity of Sound Propagation Through Solids	168
222. Reinforcement of Sound by a Resonant Board	169
223. Sound Produced by Motions in all Bodies That Can Vibrate in the Same Time Intervals	170
224. Vessels Can be Broken by the Voice, According to Some Authors . . .	170

Part IV On the Sensation of Sound: On the Hearing of Men and Animals

Section 1: Human Hearing	173
A. The Structure and Functions of the Hearing Organs	173
225. Explanations	173
226. Position and Parts of These Organs	173
227. The Outer Ear	173
228. The Auditory Meatus	174
229. The Tympanic Cavity	174
230. The Labyrinth	175
231. The Auditory Nerve	175
232. Ordinary Transmission of Impressions to the Inner Ear	176
233. Transmission of Impressions by the Solid Part of the Head	176
234. The Impressions Act on the Entire Labyrinth	176
235. Authors Consulted	177
B. The Subject of Hearing	177
236. The Ear Records the Sensation of All Sufficiently Rapid and Sufficiently Intense Disturbances	177
237. It Records the Sensation of the Relative Frequency of the Vibrations	178

238. Very Small Differences from the Exact Ratios of Tones Are Not Perceptible to the Ear	179
239. Ordinarily, the Shape of a Sounding Body and Its Mode of Vibration Cannot Be Determined by Hearing	179
240. Timbre and Articulation of Sounds	180
241. Distance of a Sound	180
242. Direction of a Sound	180
Section 2: The Hearing of Different Animals	183
243. General Remarks	183
244. Essential Organs Necessary for Hearing	183
245. Auditory Organs of Cuttlefish, Octopi, and Squid	184
246. Auditory Organs of Fish	184
247. Auditory Organs of Reptiles	184
248. Auditory Organs of Birds	185
249. Auditory Organs of Mammals	185
250. Summary of the Organs Found in Different Animals	185
251. Authors Consulted	186
Appendix A: Program of the <i>Institut de France</i>, in Which a Prize Is Proposed for the Mathematical Theory of Vibrating Plates	187
Appendix B: Reports on the <i>Clavicylinder</i> and on the Acoustic Research of the Author	191
Appendix C: Figures	203
Name Index	221
Subject Index	223

Translator's Introduction: Chladni and the State of Acoustics in 1800

[This introduction is adapted and has been modified from the material on Chladni found in the introductory chapters of *Sounds of Our Times: Two Hundred Years of Acoustics* by Robert Beyer. ISBN 978-0-387-98435-3. Reproduced with permission]

In 1802, Ernst F.F. Chladni (1756–1827) published, in German, *Die Akustik*.¹ Chladni himself translated the book into French, a book “in which I have abridged, changed and added a great deal.” He published this volume in 1809 as *Traité d'Acoustique*, dedicating it to Napoleon (a wise choice, no doubt, during that “sun of Austerlitz,” especially since the French government contributed funds to support the translation and revision). It is the translation of this French language volume that is presented here.²

By just glancing through *Traité d'Acoustique*, we can see several features that distinguish the book from a modern one. The first is the almost complete absence of mathematics. Acoustics, as it was studied at the time, at least, in the mind of Chladni, and aside from music and vibrating structures, was largely a science of observations and descriptions. Magnificent mathematics had been developed by Euler, d'Alembert, and Lagrange in the eighteenth century and applied by them to acoustical problems, but Chladni clearly passed over the details of this mathematics in writing his treatise.

---

¹ E.F.F. Chladni, *Die Akustik*, Breitkopf & Hartel, Leipzig, 1802.

² E.F.F. Chladni, *Traité d'Acoustique*, Courcier, Paris, 1809.

Ernst F.F. Chladni (1756–1827) (From D. Miller.³)

A second difference is the emphasis on vibrations. If one had any doubt that vibrations have long been recognized as an integral part of acoustics, a reading of Chladni would eliminate that misconception. Of the four sections of Chladni's book, the one devoted to vibrations comprises more than 60 % of the text. Propagation of sound through air and other gases covers about 15 %, while the remaining 25 % of the volume is divided among propagation in liquids and solids, musical scales, speech, and hearing. (Parenthetically we might note that, even though the period around 1800 was far from a quiet time in the world, there is virtually nothing in the book on noise).

In this book, Chladni divides the subject of acoustics into sources of sound, the passage of sound through matter, and its reception. Perhaps the first problem of sound propagation was the question of whether or not air (or other material) was necessary for sustaining its propagation. By 1800, this was thought to have been long settled. One of the oldest and most frequently repeated experiments in acoustics is the use of a bell or other mechanical source of sound in a chamber that had been evacuated to some extent. This experiment was first carried out by Sagredo in 1615, and repeated a number of times over the next 200 years, with the conclusion, as of 1800, that it had been proven that sound could not travel through a vacuum.

The next question was that of the velocity of propagation in air. By 1800, accurate measurements of the velocity of sound in air had existed for more than 150 years. However, the theoretical basis for calculation of the sound velocity in gases still remained a puzzle. For its calculation, the scientists of the day went back to Newton. Chladni, using Newton's method, cites velocities for a number of gases,

---

³ D.C. Miller, *Anecdotal History of the Science of Sound*, Macmillan, New York, NY, 1935, opposite pp. 24, 51.

such as oxygen and carbon dioxide, that come close to currently accepted values, but was far off in his estimate of the value in hydrogen—680–810 m/sec as against today's accepted value of 1240 m/sec. This problem was still not entirely settled in 1800. It must be remembered that much of our understanding of the behavior of gases, and of thermodynamics, stems from work done in the first quarter of the nineteenth century. Further progress in our knowledge of the velocity of sound had to wait for such a development.

The effect of the temperature on the velocity of propagation of sound was known qualitatively in 1800, but the precise connection had to await a better knowledge of the thermal properties of gases.

In 1800, there was virtually no knowledge of sound transmission in liquids. The velocity of sound in water had not yet been measured. However, a rather good theoretical value for this velocity is given by Young, who noted that the elasticity (we would call this the bulk modulus) of water had been measured by Canton in 1762 and found to be 22,000 times that of air. Using the elasticity data of Canton, Chladni is able to determine the sound velocity in a number of liquids with accuracy similar to that obtained for water.

A measurement of the velocity of sound in solids did exist in 1800, and is described by Chladni in this book. He compares the musical pitch emanating from a struck solid bar (undergoing longitudinal oscillations) with the pitch of the (standing) wave in a closed, air-filled pipe of the same length. Arguing that the difference is due to the difference in the two sound velocities, he comes up with values of the sound velocity. Chladni's wording is a bit obscure, and his values are too low by nearly 15 %. Nevertheless, he did demonstrate that sound velocity is considerably higher in solids than in gases or liquids.

In his discussion of echo, Chladni notes that it is possible (by having two reflecting surfaces facing one another) to have multiple echoes. He remarks that the ear is capable of distinguishing eight or nine different sounds in a single second. Therefore, when these repeated echoes take place more rapidly than eight or nine per second, he states that the phenomenon is known as resonance. We would define resonance somewhat differently today.

In considering sound intensity, Chladni notes that it depends on: the size of the sonorous body, the intensity of the vibrations of that body, the frequency of the vibrations, the distance at which the sound is heard, the density of the air, the direction in which the sound is heard, and the direction of the wind. We would recognize today that these dependences are a mixture of what we call the intrinsic intensity ($\frac{1}{2}\rho c v_0^2$, where ρ is the local gas density, c the speed of sound, and v_0 the amplitude of the displacement velocity), and such related quantities as the strength of the source, the directionality of the source, and the attenuation due to geometric spreading and sound absorption. All these quantities were not well sorted out in 1800.

In 1800, the available means for the production of sound were the human voice, musical instruments, cannons and other explosive devices, and natural phenomena such as animal sounds and thunder. It is not surprising, therefore, that Chladni (and

others of the time) used music as the basis on which to build almost all of acoustics. When dealing with vibrating strings, they were concerned with stringed musical instruments. Vibrating air columns were of interest because of organ pipes, and also various musical horns, while stretched membranes were related to drums. Almost every subject in Chladni's text is studied from the point of view of music. The great advances of theoretical acoustics in the eighteenth century were perhaps due to the common interests of music patrons, researchers, and the listening audiences.

Well before 1800, the understanding of music led to two great contributions to the science of sound. First, it emphasized the importance of ratios for different tones. The simple ratios appropriate for all the notes on the diatonic scale were known, and musicians with trained ears could easily identify the pitches of the various notes, starting from some accepted standard, such as middle C or, more commonly, the A above middle C. At the same time, it was also known that the pitch of a musical note was measured by its frequency of oscillation.

Because of earlier observations by Mersenne and Sauveur, Chladni is able to base his discussion of musical scales on the grounds of a knowledge of the frequencies involved in the tones of the scale, even though there remained some uncertainty as to what was the appropriate standard for middle C. One must note, however, that Chladni devotes most of his attention, in musical matters, to discussing ratios of frequencies of the different tones, where the quantities are far more accurate, rather than the absolute values of these frequencies. Chladni was aware that the human ear could hear tones as low as 30 Hz and up to 8000–12,000 Hz—which goes considerably beyond the range of frequencies achieved by most musical instruments.

Somewhere between the production and detection of sound is Chladni's own work on vibrating plates, since the study involved not only the production of sound by the vibrating plates, but also the experimental technique of identifying the vibrations. Chladni was well aware of the vibration of strings, and of the localization of nodal points in a standing wave, and the theoretical work of Lagrange and others gave a strong foundation to the subject. There was, however, no theory of vibrating plates.

Chladni was drawn to a study of the vibrations of plates from work done by Lichtenberg who scattered "electrified powder over an electrified resin-cake, the arrangement of the powder revealing the electric condition of the surface."⁴ In Chladni's first work, reported in 1787, he held fixed one or more points on a plate and stroked the side of the plate with the bow of a violin. In order to render the effect of the vibrations visible, he placed a little sand on the plate. The sand "was thrown aside by the trembling of the vibrating parts (of the plate) and accumulated on the nodal lines." Chladni must have been fascinated by the patterns taken on by the sand particles, a fascination that these "Chladni figures" continue to generate. In those days before photography, he included hundreds of drawings of different

---

⁴These "Lichtenberg figures" are what Chladni refers to as "electric figures" in the preface to *Traité d'Acoustique*.—JPC

modes of excitation for triangular, circular, square, and even elliptical plates, in this book.

The only instrument available for sound reception in 1800 was the ear. By the time of Chladni, the structures of the exterior and middle portions of the ear were quite well understood. Chladni recognized that the impulses of sound received in the outer ear were transmitted through the small bones (ossicles) of the middle ear, more or less faithfully, to the cochlea. While the gross features of the cochlea were well described by him, its role, so far as he was concerned, was very much that of a "black box." The sound impulses impinged on one end, and, somehow or other, the sensations were picked up by the auditory nerve at the other and transmitted to the brain. Chladni offered the (incorrect) opinion that the signals from the ossicles affected the cochlea as a whole rather than locally. Further developments in this area had to wait another century.

A phenomenon was observed in the eighteenth century that was later to have important consequences in physical acoustics, although this did not occur until much later. This is the phenomenon that was known as Tartini tones: When two musical sounds of different pitch are sounded simultaneously and loudly, a tone is heard with a pitch equal to the difference in the pitches of the two tones. Chladni and others studied the problem and concluded that it was a form of beats. Under the usual description of beats, when the difference in pitch is small (5–10 beats per second), we can distinguish them clearly. When the number of beats per second increases, we first distinguish the unpleasant sounds of dissonance, but as the number gets very large, they argued, we ultimately hear the pure tone of the difference frequency. While this interpretation was later proved to be incorrect, it satisfied the acoustics community for the next half-century.

In looking back over the period before the publication of *Traité d'Acoustique*, one is humbled by the accomplishments of acousticians who worked with an almost complete lack of anything we would call apparatus. What they had were the human voice and ear, musical instruments, bells and tuning forks, vibrating strings and plates, the basic equations developed over the years, and a great deal of ingenuity and resourcefulness. In a day when we can scarcely add numbers without a calculator, or perform an experiment without vast arrays of electronic equipment, we can only marvel at the success of their ingenuity and resourcefulness.

Robert T. Beyer

TREATISE
on
ACOUSTICS
(TRAITÉ D'ACOUSTIQUE)

by

E. F. F. CHLADNI

Doctor of Philosophy and of Law; Member of the Royal Society of Haarlem, of the Society of Friends of Natural Science of Berlin, of the Academy of Applied Science of Erfort, and of the Departmental Society of Mayence; Correspondent of the Imperial Academy of Saint Petersburg, the Royal Societies of Göttingen and Munich, of the Philomatic Society of Paris, and of the Batavian Society of Rotterdam.

PARIS – 1809

Napoleon the Great

Has Deigned to Agree

To the Dedication of this Work

After Viewing

The Fundamental Experiments

Preface

While the other branches of physics have been moving forward, acoustics has always lagged behind. The sounding vibrations of most elastic bodies were entirely unknown, and, ordinarily, only the transverse vibrations of a string have been considered. These have therefore been regarded as the basis of all harmony and we have tried to extend its laws to all other sounding bodies. The results of the research that many scholars such as Daniel Bernoulli, Euler, Lagrange, Giordano Riccati, and others conducted on various acoustical subjects were not introduced into the mass of knowledge that is expounded in treatises on physics. This is what caused me to undertake the development of this vast uncultivated field, and to uncover the laws of vibrations and their different modifications in all sorts of sounding bodies, according to the research of the principal geometricians and physicists, and according to numerous experiments. My aim was to give the results of both theory and experiment in a sufficiently clear and precise manner, so that at least the greatest part would be within the range of those who had only a slight acquaintance with physics and mathematics. Those who are more advanced will lose nothing because they will find sufficient data for further research and because I have always cited the principal works and dissertations which will serve for their further instruction.

Among the experiments whose results I have related here, there are none that I have not performed myself, and that I cannot repeat. I respect nature too much to want to attribute anything to it that would perhaps be only a play of my imagination.

Everything that is printed at the end of several paragraphs by way of the strictest justification contains notes or additions to the text of the paragraph, marked in such a way that the connection of the materials should suffer the least interruption.⁵

In publishing this *Treatise on Acoustics*, I am responding to the desires of several persons whose commendations and kindnesses provide a powerful motive for me to attempt to merit them by such useful work in science. I am especially honored by

---

⁵ In this edition, these notes appear in a greyed-in box.—MAB

the fact that I have been brought to this purpose by the illustrious author of *Celestial Mechanics*, who is also respected for his benevolence and his zeal in encouraging those who work in the sciences, as well as by what he has done for the increase in human knowledge. My German work could not be translated into another language without some appropriate changes; another translator would perhaps have problems of his own, and he might have had me saying something that I did not say.⁶

Therefore, I have undertaken this work myself. It must therefore be excused if a stranger who has not spent a long time in France does not always express himself with sufficient clarity. Friends who have had the kindness to preview my work have corrected some of the mistakes; I do not know if outside critics will be as indulgent as my friends; however, if they wish to be fair, they will spend more time on the subject than on the language. It has often been asked, by what chance did I happen to make certain discoveries. But chance has never favored me; to be successful I had, nearly always, to employ opinionated perseverance. Following the advice of several estimable persons, I must add here some remarks concerning the story of my discoveries, these being the result of individual circumstances. I believe that these circumstances should interest a number of readers.

My father (First Professor of Law at Wittenberg in Saxony, one of the most esteemed judicial consultants in this county because of his activity, his talent, and his probity) had provided a good instruction for me, but it was at home, and then in the provincial school of Grimme; my education therefore allowed me little liberty, so that, whereas others may recall their youth as the happiest period of their lives, I cannot say the same about mine. This continual constraint, which was not at all necessary, because I was not disposed to abuse my freedom, produced a completely contrary effect on me, imprinting an almost irresistible desire to choose my occupations myself, to travel, to struggle against adverse circumstances, and so on. Returning to Wittenberg, it was necessary, following the will of my father, for me to apply myself to jurisprudence.

After having studies at Wittenberg and at Leipzig, and having satisfied the requirements, I obtained the degree of Doctor in Philosophy and in Law at Leipzig. Fate seemed to have destined me to remain always at Wittenberg and for me to obtain employment as a Professor of Law. But, after the death of my father, I quit jurisprudence, because it conformed too little to my tastes, and applied myself principally to the study of nature, which had always been my secondary occupation, and that dearest to me. As an amateur musician, of which I had begun to learn the basic elements (a little late), in my nineteenth year, I noted that the theory of sound was the most neglected part of physics, which gave birth in me the desire of remedying this defect and of being of use to this part of physics by making a number of discoveries. In performing numerous very imperfect experiments in 1785, I had observed that a plate of glass or of metal gave off different tones when it was clamped and struck in different places, but I did not find any instruction

---

⁶These rules have been violated in the present translation, but then Chladni never undertook the translation into English. Sorry Ernst!—RTB

as to the nature of these types of vibrations. At that time, journals had given some publicity to a musical instrument, made in Italy by the Abbé Mazzochi.

This instrument consisted of glass bells to which he had applied one or two bowings of a violin; from this I conceived the idea of using the bow of a violin to examine the vibrations of different vibrating bodies. When I applied the bow to a round brass plate, stationary at its center, the plate made different sounds which, when compared with one another, were proportional to the squares of 2, 3, 4, 5, etc.; but the nature of the movements to which these tones correspond, and the means of producing each of these movements at will were still unknown to me. Experiments on the electric figures that are formed on a plate of dusted resin, discovered and published by Lichtenberg (in the *Memoirs of the Royal Society of Göttingen*), led me to presume that the different motions of a vibrating point ought also to show different appearances if one were to put a little sand or other similar material on its surface.⁷ In making use of such means, the first figure that I observed, on the round plate of which I spoke, resembled a star with 10 or 12 rays, a little like Fig. 102a, and the most acute sound was, in the series cited, the one which corresponded to the square of the number of diametral lines. One can judge my astonishment in viewing this phenomenon, which no one had previously seen. After having reflected on the nature of these motions, I did not find it difficult to vary and to multiply these experiments, from which results followed rather rapidly. My first dissertation, which contained some research on the vibrations of a round plate, of a square plate, of a ring, of a bell, etc., came out in Leipzig in 1787. The results of the research that I have carried out since that time on longitudinal vibrations and on other subjects of acoustics have appeared in several German journals and in the papers of various Societies.

Finally, after having made still more experiments and after having consulted further the research that others have performed, I joined the results together, so far as it was possible, in my *Treatise on Acoustics*, which came out in Leipzig in German [*Die Akustik*]. The present work is a translation of that book, a work that I have abridged, changed, and expanded a great deal, according to what seemed to me to be most appropriate.

It was Lichtenberg, whose ingenious ideas in physics I found most interesting, who gave a second impulse to the advance of my ideas. Being in Göttingen in 1792, I asked his opinion on the nature of fiery meteors (which are called *bolides* or fireballs), whose phenomena, such as a flame, smoke, and explosions, were little in conformity with the electrical phenomena with which they are identified. He responded that the best way of explaining these phenomena would be to attribute to these meteors an origin that is *cosmic* rather than *terrestrial*, that is to say, to suppose that it was something foreign that had arrived from the outside into our atmosphere, a little as Seneca had well explained the nature of comets, which,

---

⁷ In 1777 Lichtenberg obtained what are now called Lichtenberg figures by discharging a high voltage point to the surface of an insulator and recording the resulting radial patterns by sprinkling various powdered materials onto the surface.—JPC

nevertheless, had a long time after been regarded as atmospheric meteors until the Saxon pastor, Dörfel, had shown that Seneca was correct. Struck by this observation of Lichtenberg, I consulted works and dissertations that contained reports of similar meteors, and of stones or masses of iron that one had seen fall at one time or another as the result of a similar meteor, and I finally published my research in a dissertation that came out in Leipzig in 1794, the French translation of which, made by Eugène Coquebert-Mombret, is to be found in Vol. V of the *Journal des Mines*. I demonstrated the following observations in this paper (before the fall of rocks [meteorites] that took place at Siena on June 15, 1794).⁸ First, that the reports that had been given concerning rocks and masses of iron that had fallen with great impact as the result of a meteor fireball were not fictions or illusions, but observations of a real phenomenon; second, that these masses and these meteors were something foreign to our globe, and had arrived from the outside. In the beginning, no one agreed with me; several German critics even supposed that I had not advanced this idea seriously, but with a somewhat evil intent of seeing what fraction of physicists accepted them and how far the credulity of these individuals might extend.

In France, Mr. Pictet was the first to call to the attention of physicists as to what my paper contained (Vol. 16 of the British Library); but no one believed in the possibility of a fall of rocks until Howard's dissertation in 1802. And in 1803, the fall of rocks took place at L'Aigle, and it was established by Mr. Biot that I was not given to fits of imagination; this finding has been further demonstrated by numerous meteors which have been observed, and by the research that has been conducted. In the *Bulletin of the Philomatic Society* of April, 1809, I published a catalogue of sizeable meteors that have been observed to date, to which one could add still others that have been found; including those which Soldani has cited in Vol. 9 of the *Memoirs of the Academy at Siena*.

The invention of the *euphone* and the *clavicylinder*, and their execution under less than favorable circumstances, cost me a great deal of time, more work, and more expense than my research on the nature of sound, of which these two instruments are practical applications. Those who have worked in a similar area, as, for example, those who have tried to perfect the glass harmonica,⁹ know how many unforeseen difficulties are encountered in such work. Too often, when one wishes to put into practice those ideas which appear to conform to theory, nature, being consulted by means of experiments and tests, denies our conjectures and places insurmountable obstacles in front of us, obstacles that had not been foreseen. Then, after having worked without success for a long period of time, it becomes

---

⁸ There was an eruption of Mt. Vesuvius on June 15, 1794 near Siena, Italy, followed by the fall of a meteorite the following day, 200 km to the north.—RTB

⁹ There are two types of glass harmonica: glass harps, which consist of wineglasses rubbed by the fingers, and the armonica, invented by Benjamin Franklin, in which glass bowls are mounted on a shaft so that they rotate (partially in water) as the shaft rotates. The first type was probably most familiar to Chladni. *When the word "harmonica" is used throughout this text, it is understood to mean "glass harmonica," not the modern wind instrument.*—TDR

necessary to set aside everything that has been done and begin anew. But the least success makes us forget all these tests of our patience.

The *euphone*, invented in 1789 and perfected in 1790, consists exteriorly of small cylinders of glass that one rubs longitudinally with fingers moistened by water. These cylinders, of the thickness of a writing pen, are all of equal length, and the difference in the tone is produced by an interior mechanism. The tone resembles more that of the harmonica than that of any other instrument. In several trips that I have made to Germany, to St. Petersburg, and to Copenhagen, this instrument has received widespread approval. The one that I had with me most recently has been destroyed during the voyage by some accident, but the construction of another, on which I am now working, is almost complete.

The *clavicylinder*, invented at the beginning of 1800 and perfected since that time, consists of a keyboard, and behind this keyboard a glass cylinder, which is turned by means of a pedal and a leaden wheel. This cylinder is not itself the sounding body, as in the bells of the harmonica, but produces the tone by its rubbing of the interior mechanism. The principal quality of this instrument is its ability to prolong the sound at will with all the nuances of crescendo and diminuendo, as one augments or diminishes the pressure on the touch. The instrument is never out of tune. The reports of the Institut de France and of the Imperial Conservatory of Music, which have given very favorable judgment on this instrument, relieve me of the necessity of talking of it at length.

For some time, I have again been occupied with conducting research and experiments on different methods of constructing a *euphone* or *clavicylinder*. As the possible methods are very numerous, and as it is difficult to judge in advance the preference for one or the other, this subject will continue to keep me busy. Each invention being the property of its author, I do not merit reproach for the fact that I have still not published the internal mechanism and the construction. I have still not lost the hope that there will come a time when a compensation proportional to the sacrifices I have made will allow me to publish everything concerning the theory and construction of these instruments.

The great value that I attach to the approval of the Institut de France, and the respect that I have toward that leader of scholarly societies, whose members I have the honor of knowing personally, has encouraged me to have printed at the end of this work the prize program that it has proposed on the mathematical theory of vibrating plates and the reports that it has kindly wished to make on my research and their applications to the arts.

E.F.F. Chladni