

Vibration and Sound

Philip M. Morse

Originally published in 1936; Reprinted in 1981

TABLE OF CONTENTS

Preface to the ASA Edition
Preface to the Second Edition
Preface to the First Edition

CHAPTER I - INTRODUCTORY

Sections

1. *Definitions and Methods Units. Energy*

2. *A Little Mathematics*

The Trigonometric Functions, Bessel Functions. The Exponential. Conventions as to Sign. Other Solutions. Contour Integrals. Infinite Integrals. Fourier Transforms Problems

CHAPTER II - THE SIMPLE OSCILLATOR

3. *Free Oscillations*

The General Solution. Initial Conditions. Energy of Vibration

4. *Damped Oscillations*

The General Solution. Energy Relations

5. *Forced Oscillations*

The General Solution. Transient and Steady State. Impedance and Phase Angle. Energy Relations. Electromechanical Driving Force. Motional Impedance. Piezoelectric Crystals.

6. *Response to Transient Forces*

Representation by Contour Integrals. Transients in a Simple System. Complex Frequencies. Calculating the Transients. Examples of the Method. The Unit Function. General Transient. Some Generalizations. Laplace Transforms.

7. *Coupled Oscillations*

The General Equation. Simple Harmonic Motion. Normal Modes of Vibration. Energy Relations. The Case of Small Coupling. The Case of Resonance. Transfer of Energy. Forced Vibrations. Resonance and Normal Modes. Transient Response. Problems

CHAPTER III - THE FLEXIBLE STRING

8. *Waves on a String*

The Wave Velocity. The General Solution for Wave Motion. Initial Conditions. Boundary Conditions. Reflection at a Boundary. Strings of Finite Length.

9. *Simple Harmonic Oscillations*

The Wave Equation. Standing Waves. Normal Modes. Fourier Series. Initial Conditions. The Series Coefficients. Plucked String, Struck String, Energy of Vibration

10. *Forced Vibrations*

Wave Impedance and Admittance. General Driving Force. String of Finite Length. Driving Force Applied Anywhere. Alternative Series Form. Distributed Driving Force. Transient Driving Force. The Piano String. The

Effect of Friction. Characteristic Impedances and Admittances.

11. *Strings of Variable Density and Tension*

General Equation of Motion. Orthogonality of Characteristic Functions. Driven Motion. Nonuniform Mass. The Sequence of Characteristic Functions. The Allowed Frequencies. Vibrations of a Whirling String. The Allowed Frequencies. The Shape of the String. Driven Motion of the Whirling String.

12. *Perturbation Calculations*

The Equation of Motion. First-order Corrections. Examples of the Method. Characteristic Impedances. Forced Oscillation. Transient Motion

13. *Effect of Motion of the End Supports*

Impedance of the Support. Reflection of Waves. Hyperbolic Functions. String Driven from One End. Shape of the String. Standing Wave and Position of Minima. Characteristic Functions. Transient Response. Recapitulation. Problems

CHAPTER IV - THE VIBRATION OF BARS

14. *The Equation of Motion*

Stresses in a Bar. Bending Moments and Shearing Forces. Properties of the Motion of the Bar. Wave Motion in an Infinite Bar.

15. *Simple Harmonic Motion*

Bar Clamped at One End. The Allowed Frequencies. The Characteristic Functions. Plucked and Struck Bar. Clamped-clamped and Free-free Bars. Energy of Vibration. Nonuniform Bar. Forced Motion.

16. *Vibrations of a Stiff String*

Wave Motion on a Wire. The Boundary Conditions. The Allowed Frequencies. Problems

CHAPTER V - MEMBRANES AND PLATES

17. *The Equation of Motion*

Forces on a Membrane. The Laplacian Operator. Boundary Conditions and Coordinate Systems. Reaction to a Concentrated Applied Force

18. *The Rectangular Membrane*

Combinations of Parallel Waves. Separating the Wave Equation. The Normal Modes. The Allowed Frequencies. The Degenerate Case. The Characteristic Functions

19. *The Circular Membrane*

Wave Motion on an Infinite Membrane. Impermanence of the Waves. Simple Harmonic Waves. Bessel Functions. The Allowed Frequencies. The

Characteristic Functions. Relation between Parallel and Circular Waves. The Kettledrum. The Allowed Frequencies

20. *Forced Motion. The Condenser Microphone*
Neumann Functions. Unloaded Membrane, Any Force. Localized Loading, Any Force. Uniform Loading, Uniform Force. The Condenser Microphone. Electrical Connections. Transient Response of Microphone

21. *The Vibration of Plates*

The Equation of Motion. Simple Harmonic Vibrations. The Normal Modes. Forced Vibration Problems

CHAPTER VI - PLANE WAVES OF SOUND

22. *The Equation of Motion*

Wave along a Tube. The Equation of Continuity. Compressibility of the Gas. The Wave Equation. Energy in a Plane Wave. Intensity. The Decibel Scale. Intensity and Pressure Level. Sound Power. Frequency Distribution of Sounds. The Vowel Sounds.

23. *The Propagation of Sounds in Tubes*

Analogous Circuit Elements. Constriction. Tank. Examples. Characteristic Acoustic Resistance. Incident and Reflected Waves. Specific Acoustic Impedance. Standing Waves. Measurement of Acoustic Impedance. Damped Waves. Closed Tube. Open Tube. Small-diameter Open Tube. Reed Instruments. Motion of the Reed. Pressure and Velocity at the Reed. Even Harmonics. Other Wind Instruments. Tube as an Analogous Transmission Line. Open Tube, Any Diameter. Cavity Resonance. Transient Effect, Flutter Echo.

24. *Propagation of Sound in Horns*

One-parameter Wave. An Approximate Wave Equation. Possible Horn Shapes. The Conical Horn. Transmission Coefficient. A Horn Loud-speaker. The Exponential Horn. The Catenoidal Horn. Reflection from the Open End, Resonance. Wood-wind Instruments. Transient Effects Problems

CHAPTER VII - THE RADIATION AND SCATTERING OF SOUND

25. *The Wave Equation*

The Equation for the Pressure Wave. Curvilinear Coordinates

26. *Radiation from Cylinders*

The General Solution. Uniform Radiation. Radiation from a Vibrating Wire. Radiation from an Element of a Cylinder. Long- and Short-wave Limits. Radiation from a Cylindrical Source of General Type. Transmission inside Cylinders. Wave Velocities and Characteristic Impedances. Generation of Wave by Piston.

27. *Radiation from Spheres*

Uniform Radiation. The Simple Source. Spherical Waves of General Form. Legendre Functions. Bessel Functions for Spherical Coordinates. The Dipole Source. Radiation from a General Spherical Source. Radiation from a Point Source on a Sphere. Radiation from a Piston Set in a Sphere

28. *Radiation from a Piston in a Plane Wall*

Calculation of the Pressure Wave. Distribution of Intensity. Effect of Piston Flexure on Directionality. Radiation Impedance, Rigid Piston. Distribution of Pressure over the Piston. Nonuniform Motion of the Piston. Radiation out of a Circular Tube. Transmission Coefficient for a Dynamic Speaker. Design Problems for Dynamic Speakers. Behavior of the Loud-speaker. Transient Radiation from a Piston.

29. *The Scattering of Sound*

Scattering from a Cylinder. Short Wavelength Limit. Total Scattered Power. The Force on the Cylinder. Scattering from a Sphere. The Force on the Sphere. Design of a Condenser Microphone. Behavior of the Microphone.

30. *The Absorption of Sound at a Surface*

Surface Impedance. Unsupported Panel. Supported Panel. Porous Material. Equivalent Circuits for Thin Structures. Formulas for Thick Panels. Reflection of Plane Wave from Absorbing Wall.

31. *Sound Transmission through Ducts*

Boundary Conditions. Approximate Solutions. Principal Wave. Transient Waves. The Exact Solution. An Example Problems

CHAPTER VIII - STANDING WAVES OF SOUND

32. *Normal Modes of Vibration*

Room Resonance. Statistical Analysis for High Frequencies. Limiting Case of Uniform Distribution. Absorption Coefficient. Reverberation. Reverberation Time. Absorption Coefficient and Acoustic Impedance. Standing Waves in a Rectangular Room. Distribution in Frequency of the Normal Modes. Axial, Tangential, and Oblique Waves. Average Formulas for Numbers of Allowed Frequencies. Average Number of Frequencies in Band. The Effect of Room Symmetry. Nonrectangular Rooms. Frequency Distribution for Cylindrical Room

33. *Damped Vibrations, Reverberation*

Rectangular Room, Approximate Solution. Wall Coefficients and Wall Absorption. Reverberation Times for Oblique, Tangential, and Axial Waves. Decay Curve for Rectangular Room. Cylindrical Room. Second-order Approximation. Scattering Effect of Absorbing Patches.

34. *Forced Vibrations*

Simple Analysis for High Frequencies. Intensity and Mean-square Pressure. Solution in Series of Characteristic Functions. Steady-state Response of a Room. Rectangular Room. Transmission Response. The Limiting Case of High Frequencies. Approximate Formula for Response. Exact Solution. The Wall Coefficients. Transient Calculations, Impulse Excitation. Exact Solution for Reverberation.

Problems

BIBLIOGRAPHY

GLOSSARY OF SYMBOLS

TABLES OF FUNCTIONS

I and II, Trigonometric and Hyperbolic Functions.
III and IV, Hyperbolic Tangent of Complex Quantity.
V, VI and VII, Bessel Functions.
VIII, Impedance Functions for Piston.
IX, Legendre Functions.
XII, General Impedance Functions for Piston.
XIII, Absorption Coefficients

PLATES

I and II, Hyperbolic Tangent Transformation.
III, Magnitude and Phase Angles of \sinh and \cosh .
IV, Standing Wave Ratio and Phase vs. Acoustic Impedance.
V, Exact Solutions for Wave Modes in Rectangular Ducts and Rooms.
VI, Absorption Coefficient vs. Acoustic Impedance

INDEX

Preface to the ASA Edition

The first edition of *Vibration and Sound* appeared in the mid-30's. It appeared because I could find no text, to use in my class in acoustics, that combined the classical viewpoint of Rayleigh with the emerging perspective engendered by quantum mechanics and the vacuum tube. I learned by classical acoustics under Dayton Miller, when the ear was the ultimate measuring instrument and the equipment was all mechanical. When I came to MIT and took on the responsibilities of teaching the senior acoustics course, I had already become familiar with the analytic powers of wave mechanics and I began to learn the experimental potentialities of electronic equipment. Spurred by my enthusiasm for the new vistas, by the warm support of Professor Richard Fay, and by the continued interest of my students, I spent less than a year in writing the book. I am occasionally told that it helped make MIT an acoustics research center during and after World War II.

Vibration and Sound continued to be used, fairly widely, as a text for some two dozen years, going through one revision. When it came, in the 60's to make another revision, my interests had changed and it appeared that the textual popularity of the book had waned. Consequently Ingard and I wrote *Theoretical Acoustics*, incorporating much of *Vibration and Sound* but extending the material enough to make it a monograph rather than an intermediate text. Evidently the subsequent disappearance of *Vibration and Sound* was premature for, during the 70's, I received many pleas for another printing. Therefore I welcome the offer of the Acoustical Society of America to make the text available once more, and I hope that the response from the acoustical public will justify their decision.

Philip M. Morse
Winchester, Mass. June 1981

Preface to the Second Edition

The recent war induced a considerable development in the science of acoustics and in the mathematical techniques that are particularly useful in theoretical acoustics. Studies in ultrasonics have quickened interest in problems of radiation and scattering and in transient phenomena; and the rapid development of microwave techniques, which parallel acoustic techniques, has stimulated interest in the general theory of wave motion.

Reflecting these developments, the present edition of this volume includes more detail than the first edition on radiation problems and introduces the important subject of transient phenomena and the technique of the operational calculus. Both of these subjects are usually shunned because of their reputed difficulty. The writer is convinced that they are not particularly difficult conceptually, although they usually necessitate calculations of rather wearisome extent. They are here discussed with the intent to bring out fundamental ideas, rather than to ensure mathematical rigor of treatment.

In keeping with the plan of the first edition, the more difficult subjects are segregated at the terminations of each chapter, so that they need not be assigned if the book is to be used for a beginning course.

The writer is pleased to acknowledge his indebtedness to a large number of friends for valuable suggestions as to improvements in exposition grammar, arithmetic, and algebra. Some of the most obvious errors in the first edition have been corrected.

Especial thanks are owing J. R. Pellam, who has expended much time and effort in checking the manuscript and mathematics, and to Dr. Cyril Harris for his many helpful suggestions concerning subject matter.

Philip M. Morse
Upton, N.Y., January, 1948

Preface to the First Edition

The following book on the theory of vibrations and sound is intended primarily as a textbook for students of physics and of communications engineering. After teaching the introductory course in this subject at the Massachusetts Institute of Technology for several years, the author has become persuaded that there is need for a new textbook in the field.

There are, of course, many other books on the theory of sound. The author's excuse for adding another to the list is that in the past ten years the rapid growth of atomic physics has induced a complete reorganization of the science of acoustics. The vacuum tube and the other applications of electronics have provided immensely powerful tools for the measurement, recording, and reproduction of sound; tools which have revolutionized acoustic technique. Another useful tool, perhaps not so obvious, is the new mathematical technique which has been developed for the working out of quantum mechanics, and which is capable of throwing light on all problems of wave theory. The last chapter of this book is an example of the utility of these methods. In it the mathematical methods developed for the study of the radiation of light from an atom are applied to the theory of the acoustic properties of rooms.

During the recent rapid change in the science of sound, certain parts of the subject have gained and other parts have lost importance. The present book attempts to follow this change in emphasis and to discuss the new development as well as those portions of the older theory which are still important.

The book has been planned as a textbook with a twofold aim in view. The first aim, of course, is to give the student a general introduction to the theory of vibration and sound. An introductory course in this subject must of necessity be more theoretical than practical. In no other branch of physics are the fundamental measurements so hard to perform, and the theory relatively so simple; and in few other branches are the experimental methods so dependent on a thorough knowledge of theory. Since this is so, the student must first be given a physical picture of the fundamental theory of the vibration of solid bodies and the propagation of sound waves before he can appreciate the techniques used in the measurements of sound, and before he can begin to design acoustical apparatus.

The second aim is to give the student a series of examples of the method of theoretical physics; the way a theoretical physicist attacks a problem and how he finds its solution. This subject is too often neglected, especially in engineering courses. The student is usually given a series of formulas to use in standardized cases, the formulas sometimes introduced by a cursory derivation and sometimes with no derivation at all. After such a course the student is capable of using the formulas on standard problems, but he is unable to devise a new formula to use in unusual cases.

In this book the author has tried to derive every formula from the fundamental laws of physics (there are a few exceptions to this procedure) and to show in some detail the steps in these derivations and their

logical necessity. This does not mean that the mathematical machinery is given in excessive detail, but that the steps in the physical reasoning are brought out. Often generality and mathematical rigor have been sacrificed to make the chain of logic more distinct. It has been the author's experience that once the student can grasp the physical picture behind a mathematical derivation, he can himself add what extra generality and rigor he may need. Often, too, the author has supplemented or replaced the rigid and esoteric technical vocabulary by more colloquial phrases, in order to make vivid a concept, or to suggest a new point of view.

It is assumed that the student has a thorough knowledge of calculus, and some acquaintance with the fundamental laws of mechanics. A knowledge of differential equations is helpful but is not necessary, for the solutions of the various differential equations encountered are worked out in the text. Tables of the functions used are given in the back of the book.

Although the book is designed primarily as a textbook, a certain amount of material of an advanced nature has been introduced. In this way, it is hoped, the volume will be useful as a fairly complete reference work for those parts of the theory of sound which seem at present to be most important for the acoustical scientist. The advanced material has been included in the form of extra sections placed at the end of various chapters. The instructor may assign the first few sections of these chapters for the introductory course, and the student may refer to the other sections for further details when he needs them.

The author wishes to express his gratitude to Professor R.D. Fay and to Dr. W. M. Hall, whose help in choosing subject matter and methods of presentation has been invaluable. He is also indebted to Dr. J.B. Fisk for his willing and painstaking aid in correcting proof, and to many other colleagues in the Department of Physics at the Massachusetts Institute of Technology, for their many helpful suggestions.

Philip M. Morse
Cambridge, Mass., August, 1936

© Acoustical Society of America

Jun Yang as the new Editor-in-Chief of Sound & Vibration Magazine, and Prof. Yan Gao as its Executive Editor, both commencing May 8, 2018. To find out more background information about Prof. Yang and Prof. Gao, please [click here](#). If you would like to have your work be considered for publication in the upcoming issues of the refreshed and expanded S&V, you are strongly encouraged to familiarize yourself with our online submission system, and submit your manuscript as you deem it is ready. Philip M. Morse Vibration and Sound McGraw-Hill Book Company Inc. 1948 (International Series in Pure and Applied Physics) Acrobat 7 Pdf 21.8 Mb. Scanned by artmisa using Canon DR2580C + flatbed option. Identifier.