Preface	•. •	•	•	•	•	•			•		•	•	•		•	•	•	•	•	•	•	•	•		•	•	•			•	v
List of 1	Vota	atio)n:	5	•	•	•	•	•	•	•	•	•	•	٠	•	•	٠	•	•	•	•	•	•	•	•	•	•	•	•	xi
Introduc	tior	L											•		•							•									1

A. GENERAL THEORY OF RELAXATION IN FLUIDS

I. The Stokes-Navier Equations of Hydrodynamics

1.	The State of the Fluid	•	•	•			•	•	25
2.	The Equations of Motion		•						27
3.	The Linearized Hydrodynamic Equations	•	•	•	•	•	•	•	28
4.	Thermodynamic Discussion of the Compressibility					•		•	30
5.	The Linearized Wave Equation for a Nonviscous Fluid	•		•		•			32
6.	Viscosity					•	•	•	34
7.	The Stokes-Navier Equation. "Classical" Sound Absorption	٠	•	•	•	•		•	88
8.	Formal Introduction of Volume Viscosity	•					٠		47

II. General Considerations on Relaxation

9.	General Discussion of Resonance and Relaxation Phenomena	49
10.	Energy Exchange between Internal and External Degrees of Freedom as	
	Relaxation Phenomenon	55
11.	The Effect of Slow Energy Exchange on Sound Propagation	59
12.	Discussion of the Dispersion Equation	63
13.	Different Ways of Evaluating the Dispersion Curve	67
14.	The Absorption Curve	70
15.	Continuation of the Discussion of Absorption	72
16.	Continuation of the Discussion of Absorption and Dispersion: Kneser's	
	Expression. Calculation of C _{eff}	76
17,	Exact Calculation of Absorption and Dispersion	78
18.	Dependence on r. Summary of Characteristic Times	80
19.	Exchange of Energy and Relaxation Equation	83
20.	General Discussion of the Case in Which More Than One Relaxation Time	
	Exists	90
21.	The Excitation of Different Degrees of Freedom Which Behave like a Group	
	of Parallel Reactions	93
22.	Excitations of Different Degrees of Freedom Which Behave like Chemical	
	Reactions in Series. Classical Theory	105
23.	Excitation in Series, with Exchange with Translational Energy (Quantum	
	Theory)	110
24.	The Solution of the General Equations of Excitation in Series	117



25.	Relation of Dispersion and Absorption if More Than One Relaxation Time	
	Is Present. General Shape of the Curves	130
26.	Mixtures	136
27.	The Effect of Chemical Reactions	' 138
28.	Discussion of Special Cases. Various Orders of the Reaction	143
29.	Continuation of Discussion. Different Values of V' and H'	147
30.	Does the "Volume Viscosity" Provide Actual Stresses, Even if the Relaxation	
	Phenomenon is the Slow Energy Exchange with Internal Degrees of Freedom	
	or a Chemical Reaction?	156
31.	Thermodynamic Theory of Relaxation	159

III. Special Topics

32.	Scattering	•	•		•		٠	•	•		•	•	•	•	•		٠	•		•		•	•	٠	٠	٠	•	•	•	171
33.	Absorption	of	Н	ligi	Ь	In	ter	ısi	ty	S	ÓΠ	nd	I T	Na	ive	\$ •	•	•	•	•	·	•	•	•	·	٠	•	• .	•	174

B. GASES

IV. Application of the General Formulas to Gases

 34. Application of Previous Equations to Ideal Gases
37. Assumption That Only Binary Collisions are Effective
38. Low Frequency Absorption. Ratio of Relaxation Absorption to Classical
Absorption at Maximum
39. Gas Mixtures
40. Triple Collisions in Pure Gases and in Mixtures
41. Additional Absorption in Mixtures
V. Experimental Methods to Determine Velocity and Absorption of Ultrasonic Waves in Gases
42. Methods for Low Frequencies
43. The Ultrasonic Interferometer
44. Miscellaneous Methods

46. Direct Methods for Measuring Absorption and Relaxation Time 229

VI. Experimental Results in Molecules Without Electronic Excitation

47.	Translational Relaxation in Monatomic Gases	•	•	•	•		•	231
48.	Methods to Determine Rotational Relaxation Time		•	٠	•		٠	234
49.	Results for Rotational Relaxation				•	•••	•	236
50.	Oxygen, Nitrogen, Air			•				241
51.	Other Diatomic Molecules					· ·	•	244
52.	Linear Triatomic Molecules			•				246
53.	Nonlinear Triatomic Molecules and Four Atomic Molecules	•	•	•	•			253
54,	Large Molecules			•	•			255

viii

VII. Theory of Vibrational and Rotational Energy Exchange

65.	Introductory Remarks	260
56,	The Theory of Landau and Teller (Classical)	262
57.	Fundamental Quantum Consideration	267
ő 8.	Inelastic Scattering for an Exponential Interaction Potential	274
59.	Introduction of a Better Interaction Potential	278
60.	Tridimensional Case	285
61.	Discussion of Scattering	288
62.	Conclusion of the Tridimensional Calculation	295
63.	Some Numerical Data. Effect of Molecular Frequency on Low Frequency	
	Absorption	300
64,	Simultaneous Transitions in Rotational, Vibrational, and Translational	
	Energy	303
65.	Polyatomic Molecules. More Than One Vibrations Is Involved. Complex	
	Collisions	315
66.	Numerical Results for Diatomic and Linear Triatomic Molecules	321
67.	Further Numerical Discussion of the Effect of Impurities, of Complex Collis-	
	ions, and of Exact Resonance	328
68.	Polyatomic Molecules: Methane and Chlorinated Methanes	331
69.	Theory of Exchange of Rotational and Translational Energy	336
70.	Energy Transfer and the Kinetics of Chemical Gas Reactions	342
71.	Summary and Comparison of Theory and Experiment	348

C. LIQUIDS

VIII. General Review of Ultrasonic Absorption and Dispersion in Liquids

72.	Classical Absorption	353
73.	Absorption of Ultrasonic Waves in Liquids: The Situation in 1948. Pinkerton's	
	Classification of Liquids	354
74.	Developments Since 1948. Critical Review of Pinkerton's Classification	359
75.	Velocity of Sound Waves of Ultrahigh Frequency (UHF)	361

IX. Experimental Methods to Determine Dispersion and Absorption of Ultrasonic Waves in Liquids

76.	Methods for Low Frequencies	•							٠	•			• '	•	•		•	٠	•	•	365
77.	The Ultrasonic Interferometer			•	•										•						366
78.	Pulse Methods	•	•																		367
79.	Mechanical Method: Radiation	P	res	su	re	M	[ea	su	re	me	nts	ι.	•		•	•		•			368
80.	Optical Methods						•				•		•		•			•			369

X. Review of Theories of Liquids

81. Introduction	371
------------------	-----

82. Connection with Internal Pressure. Theory of Jäger		372
83. Heat Produced by Friction. Number of Collisions		375
84. Cubic Cell Model. Available Volume		377
85. Spherical Cell Model. "Free Volume" According to Thermodynamics.		379
86. Spherical Cell Model. The Motion Treated as Simple Harmonic Motion		381
87. The Distribution Function; Calculation of η and η'		383
88. The Relaxation Time of the Distribution. Green's Theory		385
89. Brillouin's Theory of Viscosity		393
90. Eyring's Theory of Viscosity		395
91. The Theory of Bulk Viscosity by Gierer and Wirtz		398
92. Theory of Relaxation Time. Theory of Absolute Reaction Rates	•	400

XI. Kneser Liquids

93.	Discussion of Specific Heats in Nonassociated Organic Liquids with Molecules	
	of Moderate Size	404
94.	A Cooperative Theory of Relaxation Time for Kneser Liquids	405
95.	Comparison of Relaxation Time in the Gaseous and Liquid States. Thermal	
	Relaxation as due to Interaction between a Pair of Molecules	406
96.	Temperature Dependence of the Absorption in Kneser Liquids	411
97.	Carbon Disulfide CS ₂	412
98.	Relaxation due to Rotational Isomerism	417
99.	Liquid Mixtures	425

XII. Associated Liquids and Liquids with High Viscosity

100. The Theory of Hall	428
101. Eucken's Theory of the Constitution of Water	432
102. The Effect of Pressure on Sound Absorption in Water	435
103. The Associated Liquids (Other than Water) and the Glassy State	439
104. Elastic Moduli of Liquids	446
105. Distribution of Relaxation Times	454
106. Absorption and Dispersion Measurements in Glycerol	457
107. Absorption and Dispersion in n-Propyl Alcohol	461
108. Transversal or Shear Waves in Liquids	466
109. Compressional Relaxation in Associated Liquids. Comparison with Shear	
Relaxation	475
110. Velocity Dispersion in Associated Liquids	479
111. Numerical Relationships Between the Moduli.	483
112. The Temperature Dependence of Elastic Moduli of Liquids	486
113. The Origin of Volume Viscosity in Associated Liquids	490
114. The Relation of Ultrasonic and Dielectric Relaxation Times	498
115. Ultrasonic Hysteresis at High Frequencies	503
116. Dissociation of Dimers: Acetic and Propionic Acids	505
117. Mixtures Containing Associated Liquids	509
118. Effect of Pressure on Ultrasonic Relaxation in Liquids	512
Author Index	517
Subject Index	524

x