HEARING

A
21st Century Paradigm

Including Excerpts from

THE ELECTROLYTIC THEORY OF THE NEURON

James T. Fulton
1-(949) 759-0630
jtfulton@hearingresearch.net

Hearing Concepts
1106 Sandpiper Dr.
Corona Del Mar, CA. 92625

ISBN: In Process
Library of Congress Catalog Card No.: In Process
The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (R1997)(Permanence of Paper)

Activa is a trademark of HEARING CONCEPTS, James T. Fulton, President, for an active electrolytic semiconductor device. Patent rights have been obtained; United States Patent #5,946,185

Overview of the Chapters

I. Introduction to Biological Hearing 1
A review of the state of hearing research at the current time and discussion of the tools needed to move the field forward.

2. The configurations of the hearing modality 29
A detailed look at the scope of the human hearing system and the materials and techniques used to implement it

3. The Electrolytic Theory of the Neuron/Synapse 65
The first application of the electrolytic theory of the neuron to hearing and a review of the new insights available. This new paradigm replaces the chemical theory of the neuron.

4. General and Inner Ear Physiology 109
The first presentation describing the detailed operation of the labyrinth, cochlea and cochlear partition based on first principles. The new paradigm based on acoustic dispersion within the tectorial membrane replaces the prior, largely conceptual, resonance within the basilar membrane paradigm developed most broadly by von Bekesy. The new paradigm is the first to offer any explanation for the rapid attenuation of frequency above the best frequency of an individual neurological channel.

5. Stage 1 Signal Generation 201
The first presentation describing the detailed performance of both the inner and outer hair cells in their respective sensory roles, including their dynamic roles.

6. Stage 2, Signal Processing 263
The architecture and both signal convergence and signal divergence encountered in the analog signaling portion of the peripheral neural system of hearing.

7. Stage 3 Signal Projection 293
The techniques employed to convert analog signals into action potential pulse streams for efficient signal projection and the special histographic techniques required to understand the encoding/decoding mechanisms are presented.

8. Stages 4, 5 & 6: Signal Manipulation, Cognition & Response 353
The first description of the mechanisms and methods used to extract information from the signal streams presented to the CNS, along with the first appearance of "attention" in the neural system. Insights from the acoustic imaging capability of the dolphins contribute to understanding the human hearing system.

Appendix A: Glossary 449
A glossary providing uniquely precise definitions of many terms, some (such as timbre and two distinct forms of pitch) made available for the first time by the new paradigm.

Index 471

Table of Contents

Preface xv

I Introduction to Biological Hearing 1
1.1 Introduction 1
1.1.1 The task of the biological sensory systems 1
1.1.2 The goal of this work 3
1.1.3 A formal definition of hearing 3
1.1.4 State of the Hearing Research art 4
1.1.4.1 Historical background 4
1.1.4.2 A brief technical background 5
1.1.4.3 Major impediments to advancing the theory of hearing 6
1.1.4.4 Other theories of frequency discrimination within the cochlea 7
1.1.4.5 Categorizing prior frequency discrimination proposals 8
1.1.5 The acoustic environment 8
1.1.5.1 Compression (or bulk) wave propagation 10
1.1.6 Scope, Theory, and findings of this work 10
1.1.6.1 The basic premise of this work 11
1.1.6.2 Compatibility with the prior literature 12
1.1.6.3 Fundamental findings of this work 12
1.1.7 A comprehensive performance requirement and technical description of hearing . . . 14
1.1.7.1 The operational regimes, modes and stages of hearing 14
1.1.7.2 A brief conventional requirement for hearing 15
1.1.7.3 Top level functional performance specifications of hearing 15
1.1.7.4 Second tier, technical, performance specifications of human hearing . . . 16
1.1.7.5 Third tier, implementation specifications for human hearing 17
1.1.8 The evolution of Biological Hearing 18
1.2 Important tools and ground rules in Hearing Research 20
1.2.1 Modeling of Neurological Systems 20
1.2.1.1 Ramifications of linear versus nonlinear systems 20
1.2.1.2 Adopting the Laws of Maxwell instead of Kelvin 21
1.2.2 Maintaining consistent units in neurological research 21
1.2.2.1 The definition of acoustic power and intensity levels 21
1.2.2.2 Formalizing the concept of impedance 22
1.2.2.3 Describing hydraulic situations precisely 24
1.3 The baseline models of the auditory system 24
1.3.1 The top level block diagram 24
1.3.1.1 A comparison of the physiological model of vision and hearing 26
1.3.2 The top level schematic diagram 27

2 The configurations of the hearing modality 29
2.1 Introduction 29
2.2. A brief anatomical background 30
2.2.1 Gross anatomy of the peripheral auditory system 31
2.2.2 Gross anatomy of the CNS related to hearing 34
2.2.2.1 Terminology is in a state of flux 34
2.2.2.2 The architectonics of the temporal lobes 36
2.2.3 Gross anatomy of the brainstem related to hearing 36
2.2.3.1 The cortex of lower mammals 38
2.3 The morphology of the PNS of human hearing 39
2.3.1 Morphogenesis of the auditory system 39
2.3.2 The outer ear 41
2.3.3 An expanded definition of the middle ear 41
2.3.4 The morphology of the inner ear–the cochlea 43
2.3.4.1 Gross morphology of the cochlea 43
2.3.4.2 Gross morphology of the scala media 44

2.3.4.3 The cross-sectional morphology of the cochlea 45
2.3.4.4 The morphology of the cochlear duct–scala media 47
2.3.4.5 The morphology of the Organ of Corti 47
2.3.4.6 The fluids of the cochlea 49
2.3.5 The morphology and physical properties of elements of the cochlear partition 50
2.3.5.1 The physical properties of the *static* tectorial membrane 50
2.3.5.2 Details of the morphology of the reticular lamina 51
2.3.6 The morphology of the spiral ganglia and the auditory nerve 51
2.3.7 The morphology of the cochlear nucleus 52
2.4 The physiology of the auditory system 52
2.4.1 Functional stages in hearing 53
2.4.2 The gross signaling paths of the auditory system 54
2.4.2.1 The top level schematic of the ascending paths 54
2.4.2.2 Top level block diagram of the ascending neural paths 57
2.4.2.3 The descending neural paths of the peripheral hearing system 60
2.4.3 Neural signal processing and manipulation are performed in the analog domain 60
2.4.3.1 The dominance of analog neurons within the neurological system 60
2.4.3.2 Limiting the "all-or-nothing" concept of neural activity to stage 3 61
2.5 The complexity of the human CNS based on parts count 61

3 The Electrolytic Theory of the Neuron/Synapse 65
3.1 Introduction 65
3.1.1 Background 66
3.1.1.1 The electrolytic versus ionic argument of neuron operation 66
3.1.1.2 A redefinition of neuro-active substances 67
3.1.2 The genesis of the neuron–an introductory scenario 68
3.1.2.1 Important features of the eukaryotic cell 68
3.1.2.2 The creation of active devices within a biological environment 69
3.1.2.3 The Activa, the active semiconductor device of biology 72
3.1.2.4 Specialized plasmalemmas of the neuron 72
3.1.2.5 The molecular structure of the junction between two membranes 73
3.1.2.6 A preview of neuron morphologies based on the electrolytic theory 74
3.1.2.7 The neuron as an electrolytic circuit 75
3.1.2.8 The elaboration of a eukaryotic cell into a complete neuron 76
3.1.3 The fundamental architectures of the neuron and nerves 77
3.1.3.1 The fundamental neural signaling path of biological systems 77
3.1.3.2 Neuron/nerve architectures are stage specific 78
3.1.4 The common cytological and morphological characteristics of neurons 79
3.2 A functional pyramid cell as an exemplar of a *type 1* (electrotonic) conexus 80
3.2.1 The cross-section of a typical pyramid cell 81
3.2.2 Interior features of the neuron 83
3.2.2.1 The electrical conduits within the neuron 83
3.2.2.2 The role of the vesicles 84
3.2.2.3 Diffusion within the plasmas & surrounding fluids 85
3.3 More complex analog neuron configurations 85
3.3.1 The auditory sensory neurons 86
3.3.2 The fully elaborated auditory sensory neuron 86
3.4 A modified pyramid cell as an exemplar of a *type 2* (phasic) conexus 88
3.5 The metabolic and metabotropic processes supporting the neurons 88
3.5.1 The basic electrostenolytic process supporting neurons 89
3.5.2 The Electrostenolytic Process replaces the "ion-pump" 89
3.5.3 Metabolic processes related to the operation of the neuron 90
3.5.4 The description of materials affecting neural operation 93
3.5.4.1 The redefinition of neuro-facilitators and neuro-inhibitors 93
3.5.4.2 Other putative glutamate receptors found on the plasmalemma 95
3.5.4.3 The redefinition of -ergic chemicals and neurons 95
3.6 The synapse and Node of Ranvier 96
3.6.1 Background 96
3.6.2 The synapse, an active electronic device at a deceptive location 97
3.6.2.1 Measured electrical performance of the synapse 99
3.6.2.2 The cytology of the synapses with the sensory neurons 99

3.6.3 The detailed cytological structure of the synapse 100
3.6.3.1 A redefinition of the physiology of a synapses 100
3.6.3.2 The physical and intrinsic electrical symmetry of the synapse 102
3.6.4 The Node of Ranvier, a specialized synapse 103
3.6.5 A reversible synapse current challenges the chemical theory 103

4 General and Inner Ear Physiology 109
4.1 Introduction 109
4.1.1 Historical Background 110
4.1.2 Introduction to the comprehensive theory & model of this work 111
4.1.3 Overview of the auditory system physiology 113
4.1.3.1 Physiological stages of hearing 113
4.1.3.2 Overview of the physiology of the signaling paths 114
4.1.3.3 The coding of neural signals in hearing 115
4.1.4 Technical Background–Formalizing and extending earlier concepts 117
4.1.4.1 Replacing phase-locking with the underlying transfer function 117
4.1.4.2 Differentiating between tonal and envelope channels 117
4.1.4.3 Delay is a critical parameter associated with neural signals 118
4.1.4.4 The cochleotopicity, tonotopicity, receptivity, etc. in hearing 118
4.1.5 The physics and applied mathematics supporting earlier theories 119
4.1.5.1 Background 119
4.1.5.2 Modes of vibration in physical systems 119
4.2 The physiology of the acousto-mechanical portion of human hearing 124
4.2.1 Introduction 124
4.2.2 Overview of signal conditioning in acousto-mechanical stages A, B & C1 125
4.2.2.1 Rationalizing the acousto-mechanical interfaces of hearing 125
4.2.2.2 The load impedance is critically important in hearing operations 126
4.2.2.3 Stage A--Signal conditioning by the outer ear 127
4.2.2.5 Stage B--Signal conditioning by the middle ear 127
4.2.2.6 Stage C1–Gross signal conditioning within the labyrinth 130
4.3 Stage C2–Acousto-mechanical signal conditioning in the cochlear partition 134
4.3.1 Technological overview leading to the proposed operation of the cochlea 135
4.3.2 Overview of the operation of the cochlear partition 135
4.3.2.1 Updating the physiology and topology of the signal extraction 136
4.3.2.2 Energy flow from the oval window to the sensory neurons 137
4.3.3 Physical description of the cochlear partition/Organ of Corti 140
4.3.3.1 Structural and dynamic environment of the cochlear partition 140
4.3.3.2 The curved longitudinal form of the cochlear partition 141
4.3.3.3 The static physical cross-section of the cochlear partition 147
4.3.3.4 The dynamic physical properties of the cochlear partition 149
4.3.3.5 The unique properties of the tectorial membrane & endolymph 150
4.4 The theory of spatial (transverse) dispersion used in the inner ear 152
4.4.1 Background 153
4.4.1.1 Background resources in basic research 154
4.4.1.2 Background resources related to electronics 154
4.4.1.3 Background in applied research 155
4.4.1.4 Important features of acoustic waveguide technology 155
4.4.2 Application of SAW technology to hearing 157
4.4.2.1 Surface acoustic wave velocity in the cochlea 157
4.4.2.2 Surface acoustic wave (SAW) launchers 158
4.4.3 Spatial dispersion of energy by a curved waveguide 159
4.4.3.1 Canonical examples from the literature 159
4.5 Application of dispersion theory to the cochlear partition 160
4.5.1 A roadmap to cochlear frequency discrimination 163
4.5.1.1 The propagation of modified Rayleigh waves along the TM 166
4.5.1.2 Density of hair cells along reticular membrane 168
4.5.2 The longitudinal operation of the cochlear partition 168
4.5.2.1 Predicted IHC (broadband) channel frequency performance 169
4.5.2.2 A nomograph of cochlear partition operations 174
4.5.2.3 Longitudinal velocity of energy propagation on the gel-surface 175
4.5.3 Lateral channelization of the acoustic energy 176

4.5.3.1 Underlying performance of the frequency analyzer 176
4.5.3.2 Channelization of the dispersed acoustic energy 177
4.5.4 The theoretical vs empirical place-frequency relationship 179
4.5.4.1 Background 179
4.5.4.2 Empirical place-frequency data 179
4.5.4.3 The place-frequency relationship and Hensen's stripe in humans 179
4.5.4.4 The equation of the place-frequency relationship 181
4.5.4.5 An expanded place-frequency-delay relationship 183
4.5.4.6 A nomograph describing the propagation of acoustic energy 184
4.6 Modeling the cochlea and the Organ of Corti 185
4.6.1 First order macro-mechanical model of the Organ of Corti 186
4.6.1.1 Secondary refractive effects 186
4.6.1.2 Longitudinal macro-mechanical model of the Organ of Corti 187
4.6.1.3 Quasi-radial macro-mechanical model of the Organ of Corti 188
4.6.2 First order micro-mechanical model of the Organ of Corti 190
4.6.2.1 Transverse micro-mechanical model of the Organ of Corti 190
4.6.2.2 Micro-mechanical model of the IHC & Organ of Corti 191
4.6.3 Equivalent mass models of the mammalian cochlear partition 191
4.6.3.1 An operational description of the cochlear partition 192
4.6.3.2 The overall response of an OHC channel 194

5 Stage 1 Signal Generation 201
5.1 Introduction 201
5.1.1 Framework for analyzing the acoustic and balance sensing processes 202
5.1.2 Mechanics particular to the analysis of signal generation in hearing 202
5.1.3 The piezoelectric receptors used in multiple sensory systems 203
5.1.4 Differentiating between signals in tonal versus broadband circuits 203
5.1.5 The electrolytic theory replaces the chemical theory of the neuron 204
5.1.5.1 The major impact of temperature on hearing 204
5.1.6 The "dynamic range problem" 204
5.1.7 Framework for discussing signal levels in hearing research 205
5.1.8 The role of phase-locking and the synchronization index in hearing 205
5.1.9 Care required when interpreting frequency histograms 206
5.1.10 Future test set configurations and protocols 206
5.2 The topology & physiology of the acoustic sensory neurons 207
5.2.1 Background 207
5.2.2 Gross morphological features of the phonoreceptors of the auditory system 207
5.2.2.1 The structural packaging of the sensory neurons 208
5.2.2.2 The neurological connections to the sensory neurons 210
5.2.2.3 The mounting of the sensory neurons 210
5.2.3 Overview, the electrical topology of signal generation 211
5.2.3.1 The sensory neuron and its electrical and chemical environment 211
5.2.3.2 The fundamental phonoreceptor topology 216
5.2.3.3 Comparing the cytology and topology of the sensory cell 217
5.2.3.4 The polarity of the phonoreceptor output 219
5.2.4 The cytology and physiology of the sensory neurons 220
5.2.4.1 The interface of the reticular lamina and sensory neurons 220
5.2.4.2 The cytological structure of the sensory neurons 222
5.2.4.3 Failure mechanisms associated with the OHC 225
5.2.5 The initial transduction mechanism of the sensory neurons 225
5.2.5.1 The piezoelectric effect in signal conversion 225
5.3 The detailed electrical description of the sensory neurons of hearing 227
5.3.1 Relevant technical background 228
5.3.2 The complete sensory neuron circuit with efferent neuron interface 229
5.3.3 The static electrical performance characteristics of the sensory neurons 231
5.3.3.1 The output characteristics of the sensory neurons 232
5.3.3.2 The power supplies associated with the sensory neurons 233
5.3.3.3 The input transfer characteristic of the OHC neurons 233
5.3.4 The unit and cumulative frequency spectra of sensory neurons 233
5.3.4.1 A problem with the frequency response database 234
5.3.4.2 The intrinsic frequency response at the sensory neurons 234

5.3.4.3 The cumulative frequency response at the sensory neurons 235
5.3.5 The quiescent noise levels associated with stage 1 239
5.3.5.1 Defining the noise environment of the sensory neurons 239
5.4 The short-term temporal characteristics of the sensory neurons 239
5.4.1 The transient characteristics measurable at the axon of sensory neurons 240
5.4.2 The complete P/D Equation of transduction 241
5.4.2.1 The complete impulse solution to the P/D Equation 241
5.4.2.2 The degenerate or Hodgkin solution to the P/D Equation 243
5.4.2.3 The complete P/D response to a step or square wave 244
5.4.2.4 The variability of the absorption coefficient 244
5.4.2.5 Measured sine wave bursts illustrating the P/D equation 244
5.4.2.6 Measured P/D data for the human 245
5.4.3 The impulse response of transduction in other mammals 246
5.5 The long-term temporal characteristics of hearing 248
5.5.1 Compression in the sensory neuron response 248
5.5.1.1 A composite description of static hearing performance 250
5.5.1.2 Static stage 1 performance versus the protocol 251
5.5.1.3 A theoretical alternate to Stevens' empirical law 252
5.5.2 The dynamic temporal characteristics of the sensory neurons 252
5.5.2.1 Measuring the temporal characteristics of the sensory neurons 254
5.5.2.2 The sensor neuron circuits and mechanism of adaptation 254
5.5.3 Adaptation in an operational context 257
5.5.3.1 The dynamics of the adaptation mechanism 258
5.5.3.2 Adaptation data from the literature 258
5.5.2.3 Adaptation described in terms of excess gain 258

6 Stage 2, Signal Processing 263
6.1 Introduction 263
6.1.1 The initial topographic subdivision of stage 2 Signal Processing 263
6.1.1.1 Stage 2A Signal Processing at the sensory neurons 265
6.1.1.2 Stage 2B within the spiral ganglia remains largely undocumented 267
6.1.1.3 Stage 2C signal processing, within the cochlear nuclei 267
6.1.2 Scope of signal processing within stage 2 268
6.1.3 Terminology 269
6.2 The architecture of stage 2 signal processing 270
6.2.1 Initial stage 2A architecture based on limited morphology 270
6.2.2 The gross topology of the PNS portion of the auditory system 271
6.3 Stage 2A signal processing within the cochlear partition 273
6.3.1 Background 274
6.3.2 Neural structures interfacing with sensory neurons 274
6.4 Stage 2B signal processing within the spiral ganglia 274
6.4.1 The gross encoding of the afferent signals within the auditory nerve 275
6.4.2 The density of ganglion neurons in the spiral ganglia 275
6.4.3 Representative signals at the output of stage 2B 276
6.5 Stage 2C signal processing within/adjacent to the pons 276
6.5.1 Background 279
6.5.2 The physiology of the cochlear nucleus 280
6.5.2.1 Gross signal routing and morphology within the cochlear nucleus 281
6.5.2.2 Measurements of cumulative signals within the cochlear nucleus 282
6.5.3 Direct excitation characteristics of neurons found within the cochlear nucleus 282
6.5.4 Parametric excitation characteristics of neurons within the cochlear nucleus 283
6.5.5 A generic neural circuit comparing two one-shot neurons 288

7 Stage 3 Signal Projection 293
7.1 Introduction 293
7.1.1 The "stellite neuron" versus the stellate neuron 294
7.1.2 The "fundamental" stage 3 signaling path 296
7.1.3 Background 297
7.1.4 Types of coding used in hearing and other sensory systems 298
7.1.4.1 Terminology specific to coding/modulation 298
7.1.4.2 Specific background related to coding/modulation 299

7.1.4.3 Signals associated with summing and differencing channels 300
7.2 The morphology, cytology and topology of stage 3 projection neurons 301
7.2.1 The morphology and cytology of the stage 3 neuron 301
7.2.2 A defining morphological feature of a stage 3 ganglion neuron 302
7.3 The physiology and operation of stage 3 pulse and hybrid neurons 303
7.3.1 The generic stage 3 phasic neurons as relaxation oscillators 304
7.3.1.1 The interneuron and Node of Ranvier as regenerators 304
7.3.1.2 The detailed circuitry and operation of the Node of Ranvier 306
7.3.2 The Action Potential (AP) vs pseudo action potentials 307
7.3.2.1 Details of the generic action potential waveform 308
7.3.2.2 The effect of temperature on the action potential 309
7.3.3 Electrical operating conditions in the absence of feedback 310
7.3.4 The encoding (ganglion) neurons 310
7.3.4.1 Operation of the ganglion neuron 310
7.3.4.2 Characteristics of ganglion neurons 311
7.3.4.3 The introduction of myelin in connection with the axon 316
7.3.4.4 The introduction of the Node of Ranvier in connection with the axon . . 316
7.3.4.5 Signal input via the poditic conduit 316
7.3.4.6 Transfer function of the stage 3 encoding circuits 316
7.3.4.7 Correlation with the literature 317
7.3.5 The generic stage 3 phasic signal recovery circuits 318
7.3.6 The end-to-end transfer function for an awareness mode circuit 320
7.3.7 Providing electrical power to stage 3 neurons 322
7.4 Reformulating the concept of signal transmission in neuroscience 322
7.4.1 Background related to stage 3 neuron propagation 323
7.4.2 Replacing the excitable axolemma of Hodgkin & Huxley 325
7.4.3 Introduction to the General Wave Equation 327
7.4.3.1 Resolving an inconsistency related to physical chemistry 327
7.4.3.2 The fundamental GWE 327
7.4.3.3 Application of the GWE to neuron operations 328
7.4.4 The efficient propagation of neural signals using a Maxwellian cable 329
7.4.4.1 Background–the axon as a transmission line 329
7.4.4.2 Propagation over the ideal axon 333
7.4.4.3 The variation in reactance over a lossy coaxial cable–a real axon 334
7.4.5 The propagation velocity of a real stage 3 axon 335
7.4.5.1 Historical Background –propagation velocity of axons 335
7.4.5.2 The measured propagation velocity of an axon *in-vivo* 335
7.5 The use of statistical and graphical tools in hearing research 337
7.5.1 Applying statistical methods in hearing research 338
7.5.1.1 The extended PST histogram 339
7.5.1.2 The folded PST histogram 341
7.5.1.3 Developing the conforming PST histogram 343
7.5.1.4 Comparing the C-PST and the non-conforming PST histograms 343
7.5.1.5 The inter-pulse interval (IPI) and dual IPI histograms 344
7.5.1.6 The use of the C-PST and dual IPI histograms 345
7.5.2 Highlighting the graphical interpretation of hearing performance 347
7.5.2.1 Eliminating distortion from characteristic frequency graphs 348
7.5.2.2 Reinterpreting histograms using conforming ordinate scales 348
7.5.2.3 Adding a regularity analysis to the conforming PST histogram 349
7.6 Advanced stage 3 data related to the cortex and speech perception 349

8 Stages 4, 5 & 6: Signal Manipulation, Cognition & Response 353
8.1 Introduction 353
8.1.1 Background 355
8.1.1.1 Definition & role of Signal Manipulation 355
8.1.1.2 Duality in its many guises 357
8.1.1.3 Background related to signal manipulation within the CNS 357
8.1.1.4 Overview of information extraction in vision as an analog 360
8.1.1.5 Character of neural signals shared with vision 362
8.1.2 A generic scenario of the most capable hearing system 363
8.1.2.1 The active sonar of the bottlenose dolphin 363

8.1.2.2 Comparing the human visual and the dolphin hearing systems 364
8.1.3 Analytical techniques needed to interpret stage 4 signal manipulation 364
8.1.3.1 PST patterns frequently found in hearing 365
8.1.3.2 The difference between signal projection and receptive fields 365
8.1.3.3 The computational capacity of neural tissue in the CNS 365
8.1.3.4 The limited mathematics of signal manipulation in hearing 366
8.1.4 Spectrographic representations useful in hearing research 366
8.1.4.1 The nomenclature of spectrographs 366
8.1.4.2 The structure and harmonic content of human speech 368
8.1.5 Relevant literature 369
8.1.5.1 Material relating to the electrophysiology of the CNS 369
8.1.5.2 Material relating to potential circuit organizations of the CNS 370
8.1.5.3 The archaic paradox concerning a "fundamental frequency" 371
8.2 Stage 4 physiology versus morphology of the CNS 371
8.2.1 Introduction of new terminology 371
8.2.1.1 The changing character of inter-engine signal propagation 372
8.2.1.2 Anatomical computation replaces transcendental computations 374
8.2.2 Background 374
8.2.2.1 Morphogenic levels of the brain and their relative neural power 375
8.2.2.2 The sheet form used in the cerebral hemispheres 375
8.2.3 Top level block diagrams of stage 4 (and stage 5) 376
8.2.3.1 Top level block diagram of auditory signaling through stage 4A 381
8.2.3.2 Top level block diagram of auditory signaling through stage 4 383
8.2.3.3 Top level schematics of the CNS auditory system 385
8.2.3.4 The morphology and physiology of the mes- and di-encephalon 385
8.2.4 Baseline models for higher level signal manipulation 388
8.2.5 Overview of stage 4 functional elements 388
8.2.5.1 Reticular structures and anatomical computation 389
8.2.5.2 Characteristics of the thalamic reticular nucleus 389
8.2.5.3 The characteristics of the inferior colliculus 390
8.2.5.4 The characteristics of the PGN/pulvinar couple 394
8.2.5.5 The characteristics of the MGN/temporal couple 395
8.2.6 The unique role of the cerebellum 395
8.3 Signal manipulation within the inferior colliculus 396
8.3.1 Echolocation by dolphin sonar as an example 396
8.3.1.1 The character of reflected continuous tones 397
8.3.1.2 A conceptual inferior colliculus in the dolphin 398
8.3.2 The baseline human IC model using multiple mechanisms of source location 399
8.3.2.1 The basic circuitry of source location 401
8.3.2.2 Source location using the IHC and temporal channels of hearing 402
8.3.2.3 Source location using the OHC and spectral channels of hearing 403
8.4 Signal manipulation associated with the perigeniculate nuclei couples 404
8.4.1 Terminology related to pitch discrimination 405
8.4.2 The "imaging" operation of the PGN multidimensional correlator 406
8.4.2.1 The topology and physiology of 1st stage auditory correlation 406
8.4.2.2 The question of tonal channel resolution– quantization level 409
8.4.3 1st order performance based on the multidimensional correlator 410
8.4.3.1 Discussion of simultaneous tones and tone sequences 410
8.4.4 Multi-correlator performance related to pitch, timbre and melodies 412
8.4.4.1 History of the pitch determination process 412
8.4.5 A concise definition of perceived pitch and timbre 415
8.4.5.1 A concise definition of perceived pitch 416
8.4.5.2 A concise definition of perceived timbre 417
8.4.5.3 Perceived pitch and timbre are independent of stimulus phase 418
8.4.5.4 Second order effects related to pitch 418
8.4.5.5 The baseline model leading to complex melody perception 419
8.4.5.6 Separating tones in object space & "tones" in perception space 420
8.4.6 The Spiral Tonal Map of hearing–*the definition of perceived pitch* 421
8.4.6.1 On the subject of "*perfect pitch*" 423
8.4.7 Clarification of other concepts using the spiral tonal map 424
8.4.7.1 The JND among complex tones–*the definition of segregation* 424

8.4.7.2 Resolution of *the missing fundamental puzzle* 427
8.4.7.3 Resolution of the tritone paradox 428
8.4.7.4 The representation of *the periodicity frequency* 429
8.5 The parietal lobe at the confluence of Stages 4, 5 & 6 430
8.5.1 The saliency map at the confluence of Stages 4, 5 & 6 and other memory 431
8.5.2 The action map (motor cortex) at the confluence of Stages 5 & 6 433
8.5.3 The dynamic formation of short term memory 433
8.6 Cognition, memory and motor responses in hearing 433
8.6.1 Morphological and histological background 435
8.6.2 Electrophysiological background 436
8.6.3 Additional discussion of long term memory 437
8.6.3.1 The general requirements/features of the neurological memory 438
8.6.4 Cognition within the neocortex- -Stage 5 439
8.6.4.1 Top level requirements as guides to performance 440
8.6.4.2 Speech and music recognition 441
8.6.5 Neural response system functions- -Stage 6 441
8.6.5.1 Neural system responses involving the superior colliculus 442

Appendix A: Glossary 449

Index 471

LIST OF FIGURES

Figure 1.1.1-1 The saliency map as a point of convergence within the neural system of all animals 2
Figure 1.1.2-1 A spectrogram highlighting the features present in human audition 3
Figure 1.1.5-1 The sound environment relative to human hearing 9
Figure 1.1.8-1 A phylogenic tree of the animal kingdom plotted versus geological time 19
Figure 1.3.1-1 Top level block diagram of hearing in humans 25
Figure 1.3.1-2 A comparison of the visual and auditory system block diagrams 26

Figure 2.2.1-1 Caricature of the human auditory system (cerebellum shown dotted) 32
Figure 2.2.2-1 Four horizontal sections at the levels indicated in the insert 35
Figure 2.2.3-1 The posterior human diencephalon above the mesencephalon 37
Figure 2.3.1-1 A caricature of the labyrinth with the cochlea acoustically isolated from the vestibule 40
Figure 2.3.3-1 Expanded definition of the middle ear in terrestrial animals 42
Figure 2.3.4-1 Annotated cross-sectional view of the cochlea 43
Figure 2.3.4-2 A model of the cochlear duct molded from a human cochlea using the Born method 45
Figure 2.3.4-3 Cross-section of the cochlea showing the cochlear partition 46
Figure 2.3.4-4 Detail of the cochlear partition at the Organ of Corti 48
Figure 2.3.4-5 Schematic diagram showing innervation of the Organ of Corti 48
Figure 2.4.2-1 Top level schematic of the circuits of the auditory system within the CNS 55
Figure 2.4.2-2 Annotated ascending portion of the Top Level Block Diagram of the auditory system 59

Figure 3.1.2-1 Fundamental electrolytic junctions 71
Figure 3.1.2-2 The structure of the Activa at the atomic level 73
Figure 3.1.2-3 The fundamental morphological forms of neurons 74
Figure 3.1.2-4 The electrolytic representation of a simple multipolar neuron 75
Figure 3.1.2-5 Schematic of a complete generic neurosecretory neuron 76
Figure 3.1.2-6 The fundamental functional form of the neuron and its electrical variations 78
Figure 3.2.1-1 Caricature of the rat pyramidal cell 81
Figure 3.2.1-2 A potential map of a pyramidal type neuron 82
Figure 3.2.1-3 Cytological view of the fundamental neuron including the reticula 84
Figure 3.2.1-4 A (rod) photoreceptor synapse 84
Figure 3.3.2-1 Schematic of a complete sensory neuron of hearing 87
Figure 3.5.2-1 The electrostenolytic process powering the neural system 90
Figure 3.5.3-1 The variant of the Kreb's cycle critical to neural operation 91
Figure 3.5.3-2 Details of the metabotropism and hydraulic flow of the neuron 92
Figure 3.5.3-3 Framework for materials impacting neural operations 94
Figure 3.6.2-1 The ortho- (normal) and anti-dromic operation of a synapse 99
Figure 3.6.3-1 Simplified diagram of the physiology of the synapse 101

Figure 4.1.5-1 Acoustic energy propagation in materials 120
Figure 4.1.5-2 Acoustic (elastic) energy transmission in materials 122
Figure 4.2.1-1 The interface between the middle ear and the cochlea 125
Figure 4.2.2-1 Amplitude of air particle and stapes motion as a function of frequency 129
Figure 4.2.2-2 Caricature of the labyrinth 131
Figure 4.2.2-3 Proposed detail configuration of the vestibule and cochlear duct 132
Figure 4.2.2-4 A caricature of the physiology (and hydrodynamics) of the cochlea 133
Figure 4.3.2-1 Potential signal paths within the cochlear partition 137
Figure 4.3.2-2 The acoustic information extraction mechanism of hearing 138
Figure 4.3.3-1 The geometric description of the cochlear partition 141
Figure 4.3.3-3 Representation of cochlear partition by trigonometric, exponential and Hankel functions 144
Figure 4.3.3-4 Overlaying a Hankel function to Hensen's stripe 146
Figure 4.3.3-5 The change in the local radius of Hensen's stripe with distance 148
Figure 4.3.3-6 An alternate schematic diagram of the Organ of Corti 149
Figure 4.3.3-7 A structural model of the Organ of Corti without the bulk of the tectorial membrane 150
Figure 4.4.1-1 The ideal smoothed wedge topographic waveguide 156
Figure 4.4.2-1 The nominal time delay associated with acoustic waves in various media 157

Figure 4.4.2-2 The first and second surface SAW wave launchers 158
Figure 4.4.3-1 Environment of a curved dielectric waveguide 160
Figure 4.5.1-1 Standardized frequency selective spatial dispersion along Hensen's stripe 161
Figure 4.5.1-2 Caricature of signal extraction by the SAW filter of a human 162
Figure 4.5.1-3 A roadmap to the proposed technology of frequency selection within hearing 164
Figure 4.5.1-4 Nominal profile of the acoustic waveguide of hearing 167
Figure 4.5.2-1 A functional representation of the cochlear partition 169
Figure 4.5.2-2 The attenuation of exponential and resonant functions 171
Figure 4.5.2-3 Predicted attenuation for the human cochlea at three locations along Hensen's stripe 172
Figure 4.5.2-4 Scatter plot of the high frequency slopes of 194 neural tuning curves 173
Figure 4.5.2-5 Determination of the operating parameters of Hensen's stripe 175
Figure 4.5.3-1 Estimates of the frequency selective capability of the Organ of Corti 178
Figure 4.5.4-1 Place-frequency maps for several mammals 180
Figure 4.5.4-2 Proposed place-frequency-delay characteristic of the cochlear partition for humans 182
Figure 4.5.4-3 Longitudinal velocity of surface acoustic wave in monkey & cat 185
Figure 4.6.1-1 Overall macro-mechanical schematic 187
Figure 4.6.1-2 Longitudinal macro-mechanical model of the cochlear partition 188
Figure 4.6.1-3 The quasi-radial macro-mechanical model of the Organ of Corti 189
Figure 4.6.2-1 The first order transverse micro-mechanical model of each OHC 191
Figure 4.6.3-1 Simplified dynamic mechanical model of the Cochlear partition 193
Figure 4.6.3-2 Amplitude and phase of the displacement applied to the OHCs 195
Figure 4.6.3-3 A frequently encountered graphic purporting to show the response of a sensory neuron 196

Figure 5.2.2-1 The cytology of the outer hair cell 209
Figure 5.2.2-2 The role of Deiters cells in rigidizing the OHCs 211
Figure 5.2.3-1 The gross chemical and electrical properties of the cochlear fluids 212
Figure 5.2.3-2 The electrical and chemical environment of the sensory neuron space 213
Figure 5.2.3-3 Critical potentials and waveforms in the sensory neuron environment 213
Figure 5.2.3-4 Proposed electrical configurations within the cochlea 214
Figure 5.2.3-5 Diagram of the electrical bias circuit of the sensory neurons 216
Figure 5.2.3-6 The sensory neuron of the auditory system 217
Figure 5.2.4-1 Scanning electron micrograph of the cilia of hair cells 220
Figure 5.2.4-2 OHCs after thorough washing and without gold overcoat 221
Figure 5.2.4-3 The structural& electrical cytology of the mechanical sensory neuron 224
Figure 5.2.5-1 The sound transduction process 227
Figure 5.3.2-1 Circuit diagram of the complete phonoreceptor cell 230
Figure 5.3.3-1 Nominal static potentials of the sensory neurons of hearing 231
Figure 5.3.3-2 Potential input characteristic of the outer row OHCs of guinea pig 233
Figure 5.3.4-1 Generator potentials recorded in the cochlea of the same guinea pig 235
Figure 5.3.4-2 Two spectra from IHCs in cat 236
Figure 5.3.4-3 The response of one IHC to a series of tone pulses applied at 80 dB SPL 237
Figure 5.3.4-4 SPL required to produce a generator waveform with a 2, 5 & 10 mV pedestal 238
Figure 5.4.1-1 Comparison of operational and pathological potentials 240
Figure 5.4.2-1 The complete P/D Equation response to an impulse 241
Figure 5.4.2-2 The complete impulse solution to the P/D Equation 243
Figure 5.4.2-3 The generator potential in response to a step 244
Figure 5.4.2-4 The P/D response of a cat sensory neuron measured at a stage 3 auditory nerve fiber 244
Figure 5.4.2-5 The human audio P/D response recorded by EcoG along with stage 2 signals 245
Figure 5.4.2-6 Cochlear microphonics in the human 246
Figure 5.4.3-1 The overlay of the P/D Equation on the current profiles 247
Figure 5.5.1-1 Magnitude of the pedestal potential of an IHC 249
Figure 5.5.1-2 The response of normal ears to short tone bursts versus stimulus level 250
Figure 5.5.1-3 Input-output functions of stages 0 and 1 recorded at various locations 251
Figure 5.5.2-1 Peristimulus adaptation reported as fatigue at 1000 Hz 254
Figure 5.5.2-2 The complete circuit diagram of a sensory neuron, including power supply 255
Figure 5.5.3-1 The normal operating range of the auditory system with adaptation 257

Figure 6.1.1-1 Top level signal flow diagram of stage 2 264
Figure 6.1.1-2 Initial architecture of stage 2A signal processing in the PNS 266
Figure 6.1.1-3 Top level block diagram of stage 2C 268
Figure 6.2.2-1 Caricature of neural connections in the cochlear nucleus of the auditory system 272

Figure 6.4.2-1 Relationship between the human spiral ganglia and Hensen's stripe 276
Figure 6.5.1-1 Cutaway of the pons region showing principle neural pathways 277
Figure 6.5.2-1 Selected topology of the dorsal cochlear nucleus, DCN 281
Figure 6.5.2-2 Frontal sections through the guinea pig cochlear nuclei 282
Figure 6.5.4-1 Annotated cochlear nucleus waveforms 284
Figure 6.5.5-1 The top level circuit extracting source location in human hearing 288

Figure 7.1.1-1 Top level block diagram of hearing and the ubiquitous presence of stage 3 295
Figure 7.1.2-1 Top level description of the stage 3 signal path 296
Figure 7.1.2-2 The circuit diagram of the fundamental stage 3 neural path 297
Figure 7.1.3-1 The structure of action potential streams when encoded 300
Figure 7.2.1-1 The axon segment as a multi-terminal electrolytic cell 302
Figure 7.2.1-2 A Node of Ranvier isolated in living tissue by dissection. 303
Figure 7.3.1-1 Development of the generic stage 3 neuron 305
Figure 7.3.1-2 The electrolytic circuit of the generic stage 3 encoding neuron 306
Figure 7.3.2-1 The features of the action potential at a Node of Ranvier 309
Figure 7.3.2-2 Measured action potentials as a function of temperature 309
Figure 7.3.4-1 Mean latency of auditory nerve fibers vs best frequency 312
Figure 7.3.4-2 Synchronization of cat auditory nerve fiber discharges 314
Figure 7.3.4-3 Action potential discharge rate as a function of intensity 315
Figure 7.3.4-4 The overall transfer function of a stage 3 projection circuit 317
Figure 7.3.5-1 Generic decoding circuits of the neurological system 319
Figure 7.3.6-1 The performance of a combined ganglion cell and stellite cell of stage 3 321
Figure 7.4.4-1 A comparison of coaxial cable configurations 330
Figure 7.4.4-2 The details of signal propagation within a stage 3 signal projection neuron 331
Figure 7.4.4-3 The electrical circuits used to describe an axon (a coaxial cable) 332
Figure 7.4.4-4 The capacitance and inductance of an ideal axon segment 333
Figure 7.4.4-5 The characteristic impedance and phase velocity along an axon 334
Figure 7.4.4-6 Measured impedance (inductive & capacitive) of a real axon 334
Figure 7.4.5-1 Saltatory conduction in a normal rat ventral root fiber 336
Figure 7.5.1-1 The derivation of the PST histogram and its peculiarities 340
Figure 7.5.1-2 The transposition of a data record into a histogram in hearing 342
Figure 7.5.1-3 Rate-Intensity functions for stage 3 neurons responding to an external stimulus 343
Figure 7.5.1-4 Old and New PST histograms for a differencing channel neuron 344
Figure 7.5.1-5 A comparison of graphics discounting the chopper concept 345
Figure 7.5.2-1 Stylized PST histograms from the medial geniculate nucleus 347

Figure 8.1.1-1 Major difference in the appearance of stained histological samples 359
Figure 8.1.1-2 The general flow of signaling information extraction in mammals based on vision 361
Figure 8.1.4-1 Annotated spectrogram of human speech (narrowband filter) 367
Figure 8.1.4-2 Annotated spectrogram of human speech (wideband filter) 367
Figure 8.1.4-3 Spectrogram of speech *generation* with harmonic and pitch overlays 368
Figure 8.2.2-1 Organization of the pattern recognition system of hearing 373
Figure 8.2.3-1 Top level block diagram of hearing 378
Figure 8.2.3-2 Sub-stages of stage 4 showing functional relationships 379
Figure 8.2.3-3 Block diagram of the initial stages of hearing up to stage 4A 382
Figure 8.2.3-4 Top level block diagram for stage 4 (audio) signal manipulation 384
Figure 8.2.3-5 Functional arrangement of the posterior thalamus (or mesencephalon) 387
Figure 8.2.5-1 Scheme of the synaptic domains in the central nucleus of the cat IC 390
Figure 8.2.5-2 Major subcollicular pathways projection to the ICC 391
Figure 8.3.1-1 Average absolute location error as a function of frequency 400
Figure 8.3.1-2 The fundamental IC circuit used for source location 401
Figure 8.4.2-1 Computational anatomy and rectilinear correlation in the PGN of the thalamus 407
Figure 8.4.3-1 Estimated stage 4 correlation amplifier response @ 1 dB tone level difference 412
Figure 8.4.5-1 A set of complex waveforms varying in internal phase relationships 418
Figure 8.4.6-1 A spiral tone map describing the frequency sensitivity of human hearing 422
Figure 8.4.6-2 Subjects exhibiting absolute pitch 424
Figure 8.4.7-1 Spiral tonal map showing spreading and segregation of pitches 426
Figure 8.4.7-2 Comparison of linear harmonic and exponential harmonic sequences 428
Figure 8.4.7-3 Resolution of the "tritone paradox." 429
Figure 8.4.7-4 Superposition of two pure tones a musical fifth apart, $f_2 = (3/2) \cdot f_1$ 429

Figure 8.5.1-2 The (conceptual) saliency map as a point of convergence 432
Figure 8.6.3-1 A taxonomy of mammalian memory systems 438

PREFACE

> "Neurophysiology has at times been described as data-rich and theory-poor. The neurophysiology of hearing however may almost be described as speculation-rich and data-poor. There is a serious lack of systematic data at virtually every level of the auditory system."
>
> N. Y-S. Kiang, 1965

The above quotation from Kiang, in spite of his efforts and those of others, has changed little in the last fifty years. No subsequent work could be found in the literature satisfying Kiang's call for action. In 1998, Poon & Brugge confirmed this situation. "The full power of combining experiment and theory has yet to be unleashed on studies of the neural mechanism in the brain involved in acoustic information processing." The goal of this work is to provide the theory that explains the previously collected data and guides the next data collection cycle; this is the essence of the scientific method.

This book is complementary to the author's 2004 work, Biological Vision: A 21st Century Tutorial. It was planned to write a work on the broader subject of the neural system. However, it was quickly found that detailed knowledge of the other sensory modalities was as sparse as it had been for vision. It was not possible to write a book on the neural system that was both detailed and comprehensive. This work provides a new and both comprehensive and contiguous description of the auditory modality. A new paradigm is introduced. This paradigm introduces several new propositions incompatible with previous works.

1. It introduces the actual mechanism of frequency analysis used in biological hearing for the first time.
2. It describes in detail the circuits of the sensory neurons that create the generator waveforms at their axons.
3. It also describes the method of percept creation used in both hearing and vision for the first time.
4. It also provides the first explanation of the mechanism resulting in the poorly named "critical bands" in hearing, and it ties this mechanism to the attention mechanism.
5. It defines the method of encoding used at the lowest level within the neural system and shows that the commonly used PST histogram is inappropriate while defining a new histogram format.
6. It shows a literal interpretation of the clinical term recruitment is inappropriate.

As noted by Kuhn when he expanded the concept of paradigm, "rival paradigms are incommensurable—that is, it is not possible to understand one paradigm through the conceptual framework and terminology of another rival paradigm." A feature of a new paradigm is its frequent ability to explain paradoxes encountered in the old paradigm. Both the fundamental frequency paradox and the tritone paradox associated with the old paradigm are resolved under the new paradigm. The unresolved role of the outer hair cells within the cochlear partition under the old paradigm is clearly defined under the new paradigm, as is the operation of the cochlear partition itself. The new paradigm does not require, or support, a mechanical amplifier between the basilar membrane and the cilia.

As noted in Chapter 1, the material prepared to describe the contiguous hearing modality greatly exceeds the available space in a one volume book. As a result, this volume may appear too cryptic or overly concise in some areas. To alleviate this problem, a more verbose version of this work (that may expand into a second volume) was placed on the Internet in 2007. Where appropriate, the reader may wish to consider this volume a guide to that resource.

The overall effort was planned and written by one author to communicate a cohesive end-to-end description of the auditory system, primarily in humans, that is as complete and detailed as possible. Of necessity, the level is designed for advanced students and researchers in neurobiology, residents, and other professionals seeking current information on the biology of hearing. It originated during the preparation of a neurological text of larger scope when it became apparent that the operation of large portions of the auditory system were not adequately understood within the hearing community. It became apparent that much of the knowledge available from vision research could be applied to the auditory system.

This book could not have been written by an insider of the Hearing research community. It would have required excruciating and wrenching changes from what I would have been taught, and what my associates would tolerate in the realm of ideas. The ability of an "uninitiated" to review the available data and derive a comprehensive functional model appears to offer significant value in this situation. Uninitiated may not be an appropriate term since the author has previously performed a similar analysis on the visual system and published the most comprehensive book available on its operation. Much of that material is available on the Internet and is accessed by thousands from around the world every day.

The above methodology has provided extensive insights that were not available to the exploratory investigators at the time of their experiments. These will be presented below. The hearing system shares many of the architectural features of the vision system. Reinterpretation of the available data within this realization offers considerable verification of the proposed model, along with improved understanding of the operation of the auditory system.

Eddins & Green have discussed the difficulty of developing a mechanistic theory of how the auditory system functions[1]. They note the complexity of the system has made this a difficult task. The problem has been exacerbated by the wide range among experimental values for a given parameter found in the literature. They noted de Boer rejected all theories related to frequency analysis proposed prior to 1985 as ad hoc based on a limited data set. He proposed the community seek to replace the myriad of ad hoc models with a single, internally consistent "super-model." This work will introduce a number of improvements in the data set since then as well as a paradigm shift in the fundamental assumptions related to transduction. It also introduces the Activa, the active electrolytic semiconductor device of the neural system. The discovery of the Activa provides a common explanation to many previously unresolved issues in all areas of the neural system. As a result, this work offers a much more comprehensive and internally consistent, although still incomplete, "super-model" for Professor de Boer's consideration.

In reading the preface to "Foundations of Modern Auditory Theory" by Jerry Tobias (1972), I was intrigued by some of his thoughts. He notes, "For a long time now, I've been looking for a book that would tell me more about ears than I wanted to know. It doesn't exist. This book isn't it either, although it was devised for the purpose of filling more gaps than any of the others do." Following his publishing adventure, he noted, "Anyone who attempts to compile a treatise of the magnitude of this one has to be an eccentric—if not when he starts, then certainly by the time he's done." Let me add that the likelihood of becoming an eccentric is compounded when one chooses to write all of the text, as opposed to only editing the work of contributors as Tobias did. After encountering the same problem in vision and solving it, I also wanted to find a desk reference that explained how hearing worked.

The task appeared to revolve around the penchant of biologists and even biophysicists to rely upon the linear assumption. Belgum & Copenhagen highlighted the awkwardness of the linear assumption in 1988[2]. They described the logarithmic transfer function of the synapse graphically and in considerable detail, including using the expression "an e-fold change in the release rate of transmitter from the rod be obtained with a 2 mV change in rod potential." They then transition to a linear two-terminal model for the synaptic mechanism in their figure 7.

The Electrolytic Theory of the Neuron presented in this work is not a variant of the passive linear concept of the synapse developed in earlier works. The Electrolytic Theory was developed from fundamental concepts, involves an active element and is inherently nonlinear (primarily exponential based on the mechanisms involved). It applies to all elements of the neural system, not just the synapse.

The original debate over the chemical versus electrical character of the synapse hinged on the unidirectional character of the signal flow in the face of a bilateral (linear) description of the electrical putative network. Patch clamp data is now available showing the synapse exhibits a diode characteristic that is electrically reversible. Such performance is compatible with the Electrolytic Theory of the Neuron but is in conflict with the current putative chemical synapse which is physically asymmetric and not reversible.

My middle name is Thomas. I am the quintessential "doubting Thomas" of folklore. I must be able to answer the four basic questions about anything I encounter and become involved with; what, where, how and why. This talent, or eccentricity, has served me well. It has provided answers to many previously unknown facts during my career. This has been particularly true about the visual system, documented in my recent book, and it has now answered many previously unanswered questions about the auditory system, documented in this work.

Attempting to proceed without a sophisticated model (as opposed to a simple conceptual model) is a direct violation of "the Scientific Method." The disparate data in the literature can only be rationalized (or discarded as erroneous) based on an adequate (although possibly still incomplete) model. Lacking such a model, the data in the literature is necessarily "out of context." At the current time, the field of hearing research must be considered one of exploratory research, rather than applied research. The primary goal of this work is to provide the necessary model, place the data reviewed in its proper context, and provide visibility into the appropriate future applied research.

This book is designed to be readable by the many, with the occasional reliance upon the Glossary provided in

Appendix A. However, it is designed for the upper university through postgraduate level. The initial chapter will present some material in abbreviated form, with subsequent detail to follow. As a result, those without at least an introductory course in the morphology and physiology of animals may find it difficult to follow. On the other hand, it will introduce many engineering and mathematical concepts that are foreign to both previous and current biology curriculums. As a result, some material may appear new to even those well prepared in the biological sciences. Chapter 2 is presented with the particular purpose of acquainting the reader with the Electrolytic Theory of the Neuron. Additional mathematical concepts will be introduced periodically as the need arises throughout the work. The mathematical field of conformational transforms has been found to play a crucial role in the ability of the visual system of humans to extract features from complex two-dimensional scenes imaged on the fovea. Among other features, a conformal transformation used in vision transforms circles in object space into straight lines in the correlation space of the occipital lobe. This work will show a similar Riemann transformation is used in hearing.

The paradigm shift embodied in the Theory and models presented in this work may be difficult for many teaching academics to accept. They are frequently wedded to the material they are currently teaching. To change their position requires wrenching changes related to both their thinking and the syllabi they have worked from for years. Unfortunately, their students do not suffer these constraints. The students have proven willing to adopt the material via their exposure to it on the internet.

This work introduces a number of scientific disciplines to the study of hearing that did not exist during the first half of the 20th Century. These disciplines lead to an entirely different concept of the auditory modality than presented in the literature up to this very day. The method of energy propagation within the cochlea depends on the development of the recent field of liquid crystals (beginning in circa 1960), combined with the unique mode of energy propagation associated with the Rayleigh (surface acoustic) wave. The method of frequency selection employed in the cochlea was only recognized theoretically by Marcatili in 1969. The electrolytic nature of signal transmission within the neural system was first published by this author in 2004. Any study of hearing (whether theoretical or empirical) that does not incorporate the mechanisms associated with these technologies is obsolete, virtually by definition.

An earlier alternate electronic theory of the neuron (focused on the synapse) was suppressed by the oligarch peers of neurology during the 1950's and little material based on an electrolytic approach has been published since. This was, and remains, an unfortunate action by the neurological community. It has retarded the advancement of science concerning the sensory modalities significantly. The Electrolytic Theory of the Neuron (addressing the complete neurological system) is based on concepts concerning a state of matter unknown to the generation active at mid-century. The Electrolytic Theory of the Neuron is based on the liquid-crystalline state of matter. The liquid-crystalline state is becoming known as the fifth state of matter, following the solid, liquid, gaseous and plasma states. Currently, the success of the Electrolytic Theory of the Neuron is so advanced, it answers questions that cannot even be formulated based on the chemical theory. This fact will become overwhelmingly clear in the course of interpreting this work and its companion works on neurology and biological vision.

The Electrolytic Theory easily handles the following questions. What is the main purpose of Reissner's Membrane within the cochlear partition (Chapter 4)? Why is there an electrical potential difference of 80 millivolts between the two sides of the membrane (Chapter 5)?

It also answers another unique question that has not been answered by any other theory. "What mechanism can provide 450 dB/octave attenuation on the high frequency side of a sensory neuron response than any resonance-based circuit?" This attenuation far exceeds that achievable in any resonant circuit (Chapter 4). The unique mathematics associated with this mechanism provides strong support for the theory of frequency separation proposed in this work.

The dispersive theory of the cochlea presented here has also significantly advanced understanding at the expense of the various resonance and other traveling wave theories of the literature. It answers many questions not answered by, or beyond the scope of, these other theories. A good example is "why is the frequency response of the dispersive mechanism asymmetrical when measured at the auditory nerve?"

The reader is also asked to examine his interpretation of how the Scientific Method should build on the foundation provided by earlier investigators. Should the early work be considered a spotlight defining a narrow path forward through the darkness, or as a floodlight providing the ability to interpret the environment immediately ahead in order to gain a broader understanding? The first approach necessarily prevents examination of branches in the road and the approach of parallel investigations from outside the narrow path that may lead to the merging of ideas, the very essence of progress in science.

This work probably contains errors and inconsistencies. It certainly contains unfinished tracts. The author has not had the advantage of students to proofread every page. While it has been circulated among qualified readers, any errors are the responsibility of the author and will be corrected as soon as possible via the author's website and in future editions.

1.Eddins, D. & Green, D. (1995) Temporal integration and temporal resolution *In* Moore, B. *ed.* Hearing. NY: Academic Press pg 207
2.Belgum, J. & Copenhagem, D. (1988) Synaptic transfer of rod signals to horizontal and bipolar cells in the retina of the toad, *Bufo marinus J Physiol* vol 396, pp 225-245