

# Contents

<b>Contributors</b> .....	xv
<b>List of Abbreviations</b> .....	xix
<b>1 Microbial Senses and Ion Channels</b> .....	1
Ching Kung, Xin-Liang Zhou, Zhen-Wei Su, W. John Haynes, Sephan H. Loukin, and Yoshiro Saimi	
1.1 The Microbial World .....	2
1.1.1 Microbial Dominance .....	2
1.1.2 Molecular Mechanisms Invented and Conserved in Microbes .....	3
1.2 Microbial Senses .....	5
1.3 Microbial Channels .....	6
1.3.1 The Study of Microbial Ion Channels .....	6
1.3.2 The Lack of Functional Understanding of Microbial Channels .....	7
1.4 Prokaryotic Mechanosensitive Channels .....	8
1.5 Mechanosensitive Channels of Unicellular Eukaryotes .....	9
1.5.1 A Brief History of TRP Channel Studies .....	9
1.5.2 Mechanosensitivity of TRP Channels .....	10
1.5.3 Distribution of TRPs and their Unknown Origins. ....	11
1.5.4 TRP Channel of Budding Yeast. ....	13
1.5.5 Other Fungal TRP Homologs .....	16
1.5.6 The Submolecular Basis of TRP Mechanosensitivity – a Crucial Question .....	16
1.6 Conclusion .....	18
References. ....	19
<b>2 Mechanosensitive Channels and Sensing Osmotic Stimuli in Bacteria</b> .....	25
Paul Blount, Irene Iscla, and Yuezhou Li	
2.1 Osmotic Regulation of Bacteria. ....	26
2.1.1 Maintaining Cell Turgor with Compatible Solutes .....	27

2.1.2	Measuring Mechanosensitive Channel Activities in Native Membranes . . . . .	28
2.1.3	Getting Solutes Out of the Cytoplasm: Cell Wall, Turgor and Elasticity . . . . .	30
2.2	MscL . . . . .	31
2.3	MscS . . . . .	34
2.4	How Do Bacterial Mechanosensitive Channels Sense Osmolarity? . . . . .	38
2.5	Perspective: Other Mechanosensitive Channels from Bacteria and Other Organisms . . . . .	40
	References . . . . .	41
<b>3</b>	<b>Roles of Ion Channels in the Environmental Responses of Plants</b> . . . . .	<b>47</b>
	Takuya Furuichi, Tomonori Kawano, Hitoshi Tatsumi, and Masahiro Sokabe	
3.1	Introduction . . . . .	48
3.2	Long-Distance Signal Translocation in Plants . . . . .	49
3.3	Calcium-Permeable Channels in Plants . . . . .	53
3.3.1	Cyclic Nucleotide-Gated Cation Channel . . . . .	53
3.3.2	Ionotropic Glutamate Receptor . . . . .	56
3.3.3	Voltage-Dependent $\text{Ca}^{2+}$ -Permeable Channels . . . . .	57
3.3.4	Plant Two Pore Channel 1 . . . . .	58
3.3.5	Mechanosensitive Nonselective Cation Channel . . . . .	60
3.4	Conclusions . . . . .	62
	References . . . . .	62
<b>4</b>	<b>Ion Channels, Cell Volume, Cell Proliferation and Apoptotic Cell Death</b> . . . . .	<b>69</b>
	Florian Lang, Erich Gulbins, Ildiko Szabo, Alexey Vereninov, and Stephan M. Huber	
4.1	Introduction . . . . .	70
4.2	Cell Volume Regulatory Ion Transport . . . . .	70
4.3	Stimulation of $I_{\text{CRAC}}$ During Cell Proliferation . . . . .	71
4.4	Inhibition of $I_{\text{CRAC}}$ During CD95-Induced Lymphocyte Death . . . . .	72
4.5	Activation of $\text{Ca}^{2+}$ Entry in Apoptosis and Eryptosis . . . . .	72
4.6	Activation of $\text{K}^{+}$ Channels in Cell Proliferation . . . . .	73
4.7	Inhibition of $\text{K}^{+}$ Channels in Apoptosis . . . . .	73
4.8	Stimulation of $\text{K}^{+}$ Channels in Apoptosis . . . . .	74
4.9	Activation of Anion Channels in Cell Proliferation . . . . .	74
4.10	Activation of Anion and Osmolyte Channels in Apoptosis . . . . .	75
4.11	Conclusions . . . . .	76
	References . . . . .	77

<b>5 TRPV Ion Channels and Sensory Transduction of Osmotic and Mechanical Stimuli in Mammals</b> . . . . .	85
Wolfgang Liedtke	
5.1 Introduction: Response to Osmotic and Mechanical Stimuli – a Function of TRPV Ion Channels Apparent Since the “Birth” of this Subfamily. . . . .	86
5.2 In Vivo Findings Implicate Products of the <i>trpv1</i> Gene in Osmo-Mechano Transduction . . . . .	87
5.3 Tissue Culture Cell Data Implicate TRPV2 in Osmo-Mechanotransduction . . . . .	89
5.4 In Vivo Mouse- and Tissue Culture-Data Implicate the <i>trpv4</i> Gene in Osmo-Mechanotransduction, Including Hydromineral Homeostasis and Pain. . . . .	89
5.5 Recent Developments in Regards to <i>trpv4</i> Function: Regulation of TRPV4 Channels by N-glycosylation, Critical Role of TRPV4 in Cellular Volume Regulation and in Lung Injury . . . . .	91
5.6 Mammalian TRPV4 Directs Osmotic Avoidance Behavior in <i>C. elegans</i> . . . . .	93
5.6.1 Cloning of the <i>C. elegans</i> Gene <i>osm-9</i> – the Other Founding Member of the <i>trpv</i> Gene Family . . . . .	93
5.6.2 TRPV4 Expression in ASH Rescues <i>osm-9</i> Mechanical and Osmotic Deficits . . . . .	93
5.6.3 Proposed TRPV4 Transduction Mechanism in <i>osm-9 ash::trpv4</i> Worms . . . . .	95
5.7 Outlook for Future Research on TRPV Channels . . . . .	96
References. . . . .	97
<b>6 Mechanisms of Thermosensation in TRP Channels</b> . . . . .	101
Karel Talavera, Thomas Voets, and Bernd Nilius	
6.1 Introduction . . . . .	102
6.2 A Short Description of the TRP Channel Superfamily . . . . .	102
6.3 Mechanisms of Thermosensitivity in ThermoTRPs . . . . .	104
6.3.1 Some Theoretical Basics of Ion Channel Thermodynamics . . . . .	104
6.3.2 Thermodynamics of Channel Gating in the Presence of an External Field: Voltage-Gated Channels . . . . .	107
6.3.3 The Principle of Temperature-Dependent Gating in TRPV1 and TRPM8. . . . .	108
6.3.4 Heat-Induced Activation of TRPM4 and TRPM5: Sweet Confirmation of the Principle . . . . .	113
6.4 Most ThermoTRPs are Little Understood . . . . .	114
6.4.1 ThermoTRPVs are Still Hot . . . . .	114

6.4.2	TRPA1 Channels: Close Cousins with Different Thermosensation . . . . .	116
6.4.3	Last, But Not Least: TRPM2 . . . . .	116
6.5	Concluding Remarks . . . . .	117
	References . . . . .	117
<b>7</b>	<b>TRPC Family of Ion Channels and Mechanotransduction . . . . .</b>	<b>121</b>
	Owen P. Hamill and Rosario Maroto	
7.1	Introduction . . . . .	122
7.2	Distinguishing Direct from Indirect MS Mechanisms . . . . .	123
7.2.1	Stretch Activation of Channels in the Patch . . . . .	123
7.2.2	Osmotic Swelling and Cell Inflation . . . . .	123
7.2.3	Gating Kinetics . . . . .	124
7.2.4	The Use of MS Enzyme Inhibitors . . . . .	125
7.2.5	Reconstitution of MS Channel Activity in Liposomes . . . . .	125
7.3	Extrinsic Regulation of Stretch Sensitivity . . . . .	126
7.4	Stretch Sensitivity and Functional MT . . . . .	126
7.5	General Properties of TRPCs . . . . .	127
7.5.1	TRPC Expression . . . . .	127
7.5.2	TRPC Activation and Function: Mechanisms of SOC and ROC . . . . .	128
7.5.3	TRPC–TRPC Interactions . . . . .	129
7.5.4	TRPC Interactions with Scaffolding Proteins . . . . .	130
7.5.5	TRPC Single Channel Conductance . . . . .	131
7.5.6	TRPC Pharmacology . . . . .	133
7.6	Evidence of Specific TRPC Mechanosensitivity . . . . .	133
7.6.1	TRPC1 . . . . .	133
7.6.2	TRPC2 . . . . .	138
7.6.3	TRPC3 . . . . .	139
7.6.4	TRPC4 . . . . .	139
7.6.5	TRPC5 . . . . .	140
7.6.6	TRPC6 . . . . .	141
7.6.7	TRPC7 . . . . .	144
7.7	Conclusions . . . . .	145
	References . . . . .	147
<b>8</b>	<b>Mechano- and Chemo-Sensory Polycystins . . . . .</b>	<b>161</b>
	Amanda Patel, Patrick Delmas, and Eric Honoré	
8.1	Introduction . . . . .	162
8.2	Role of the Heteromer PKD1/PKD2 in Mechanotransduction . . . . .	164
8.3	Role of the Heteromer PKD1L3/PKD2L1 in Chemoreception . . . . .	168
	References . . . . .	171

<b>9 Biophysics of CNG Ion Channels</b> . . . . .	175
Peter H. Barry, Wei Qu, and Andrew J. Moorhouse	
9.1 Introduction . . . . .	176
9.2 Physiological Function of Retinal and Olfactory CNG Channels. .	176
9.2.1 Visual Transduction . . . . .	176
9.2.2 Olfactory Transduction . . . . .	179
9.3 Subunit Composition of CNG Channels . . . . .	180
9.4 Structure of the CNG Channel Pore . . . . .	182
9.5 Activation of CNG Channels . . . . .	183
9.6 Permeation and Selectivity of CNG Channels. . . . .	186
9.6.1 General Methodologies for Permeation Measurements . . .	187
9.6.2 Permeation Parameters in Native and Recombinant CNG Channels . . . . .	188
9.6.3 Structural Basis of Ion Permeation and Selectivity in Recombinant CNG Channels. . . . .	194
9.7 Conclusion . . . . .	197
References. . . . .	197
<b>10 Sensory Transduction in <i>Caenorhabditis elegans</i></b> . . . . .	201
Austin L. Brown, Daniel Ramot, and Miriam B. Goodman	
10.1 Introduction . . . . .	202
10.1.1 <i>C. elegans</i> as a Simple Sensation-Action Machine. . . . .	202
10.1.2 The Senses of the Worm . . . . .	203
10.1.3 Methods Used to Study Sensory Transduction Genes in <i>C. elegans</i> . . . . .	205
10.1.4 Ion Channel Families That Sense in the Worm. . . . .	205
10.2 Mechanosensation and Mechanotransduction. . . . .	206
10.2.1 Somatosensation . . . . .	206
10.2.2 Nose Touch . . . . .	210
10.2.3 Proprioception . . . . .	211
10.2.4 Male-Specific Mechanotransduction. . . . .	211
10.3 Thermotransduction. . . . .	212
10.3.1 <i>C. elegans</i> Temperature-Guided Behaviors. . . . .	212
10.3.2 A Neural Circuit for Detecting and Processing Temperature. . . . .	213
10.3.3 cGMP Signaling is Critical for AFD Thermotransduction. . . . .	213
10.3.4 Subcellular Localization of the Transduction Apparatus. . . . .	214
10.3.5 Similarities to Vertebrate Vision . . . . .	215
10.4 Chemosensation and Chemotransduction . . . . .	215
10.4.1 CNG Channels in Chemotransduction . . . . .	215
10.4.2 TRP Channels in Chemotransduction . . . . .	216
10.4.3 Oxygen Sensing and Aerotaxis . . . . .	216

10.5 Polymodal Channels and Nociception . . . . .	217
10.6 Conclusion . . . . .	218
References . . . . .	218
<b>11 Epithelial Sodium and Acid-Sensing Ion Channels. . . . .</b>	<b>225</b>
Stephan Kellenberger	
11.1 Introduction . . . . .	226
11.2 Overview of the ENaC/DEG Channel Family . . . . .	226
11.3 Localisation and Physiological Role . . . . .	228
11.3.1 The Epithelial Na <sup>+</sup> Channel . . . . .	228
11.3.2 Acid-Sensing Ion Channels . . . . .	230
11.4 Structural Aspects . . . . .	233
11.4.1 Primary Structure and Membrane Topology of Channel Subunits . . . . .	233
11.4.2 Multimeric Channels and Subunit Stoichiometry . . . . .	233
11.5 Ion Conduction and Channel Pore . . . . .	235
11.5.1 Biophysical and Pharmacological Properties . . . . .	235
11.5.2 Structure-Function Relationship of the Ion Permeation Pathway . . . . .	236
11.6 Channel Gating and Regulation . . . . .	237
11.6.1 Channel Gating . . . . .	237
11.6.2 Regulation of Channel Expression and Function . . . . .	238
11.6.3 Gating and Regulatory Domains . . . . .	240
11.7 Conclusions . . . . .	241
References . . . . .	242
<b>12 P2X<sub>3</sub> Receptors and Sensory Transduction . . . . .</b>	<b>247</b>
Charles Kennedy	
12.1 Introduction . . . . .	248
12.2 P2X Receptor Subtypes . . . . .	248
12.2.1 Discovery of Subtypes . . . . .	248
12.2.2 Homomeric P2X Receptors . . . . .	249
12.2.3 Heteromeric P2X Receptors . . . . .	251
12.3 P2X Receptors in Sensory Nerves . . . . .	252
12.3.1 Sensory Nerves . . . . .	253
12.3.2 P2X Receptor Expression in Sensory Nerves . . . . .	253
12.3.3 Functional Expression in Sensory Nerves . . . . .	254
12.4 Physiological Roles for Sensory P2X Receptors . . . . .	257
12.4.1 Filling of the Urinary Bladder . . . . .	257
12.4.2 Sensing of Blood O <sub>2</sub> and CO <sub>2</sub> Levels . . . . .	258
12.5 ATP and P2X <sub>3</sub> Receptors in Chronic Neuropathic and Inflammatory Pain . . . . .	258

12.5.1 Down Regulation of P2X <sub>3</sub> Receptors . . . . .	258
12.5.2 A-317491 – a P2X <sub>3</sub> Antagonist . . . . .	260
12.6 Mechanisms Underlying Chronic Pain . . . . .	260
References . . . . .	263
<b>13 Voltage-Gated Calcium Channels in Nociception . . . . .</b>	<b>267</b>
Takahiro Yasuda and David J. Adams	
13.1 Introduction . . . . .	268
13.2 Calcium Channel Structure, Gene Family and Subunit Composition . . . . .	268
13.2.1 Gene Family of $\alpha_1$ Subunits . . . . .	270
13.2.2 Membrane Topology and Functional Motifs of $\alpha_1$ Subunits . . . . .	271
13.2.3 Auxiliary $\beta$ and $\alpha_2\delta$ Subunits . . . . .	273
13.2.4 Regulation of Macroscopic Current Amplitude by Auxiliary Subunits . . . . .	274
13.3 Physiological Roles of Calcium Channels in Neuronal Function . . . . .	276
13.4 N-Type Calcium Channel Diversity . . . . .	277
13.4.1 N-Type Calcium Channel Splice Variants . . . . .	278
13.4.2 N-Type Calcium Channel Sensitivity to $\omega$ -Conotoxins . . . . .	279
13.5 N-Type Calcium Channels in Nociception and Neuropathic Pain . . . . .	280
13.5.1 Electrophysiology and a Role for N-Type Calcium Channels in Sensory Neurons . . . . .	280
13.5.2 N-Type Calcium Channel Splice Variants in Sensory Neurons . . . . .	282
13.5.3 Pathophysiological Role of N-Type Calcium Channels in Pain – Therapeutic Target for Neuropathic Pain . . . . .	283
13.5.4 Endogenous Modulation of N-Type Calcium Channel-Mediated Nociception . . . . .	286
13.6 Conclusion . . . . .	287
References . . . . .	287
<b>Index . . . . .</b>	<b>299</b>



<http://www.springer.com/978-3-540-72683-8>

Sensing with Ion Channels

Martinac, B. (Ed.)

2008, XXIII, 304 p., Hardcover

ISBN: 978-3-540-72683-8