

- **Preface** (p. v)
- **1 Measurement Systems** (p. 1)
 - **1.1 Studying Biomedical Engineering** (p. 2)
 - **1.1.1 Scales of Biological Organization** (p. 2)
 - **1.1.2 Fields of Biomedical Engineering** (p. 3)
 - **1.1.3 Fields of Biological Science** (p. 5)
 - **1.1.4 Workplace Environments for Biomedical Engineers** (p. 6)
 - **1.2 The Need for Bioinstrumentation** (p. 6)
 - **1.2.1 The Scientific Method** (p. 6)
 - **1.2.2 Clinical diagnoses** (p. 7)
 - **1.2.3 Feedback in Measurement Systems** (p. 7)
 - **1.3 Instrumentation** (p. 8)
 - **1.3.1 Measurands** (p. 8)
 - **1.3.2 Sensors** (p. 9)
 - **1.3.3 System Characteristics** (p. 11)
 - **1.3.4 Outputs** (p. 14)
 - **1.3.5 Panels and Series** (p. 15)
 - **1.4 Errors in Measurements** (p. 15)
 - **1.4.1 Sources of Error** (p. 15)
 - **1.4.2 Accuracy and Precision** (p. 16)
 - **1.4.3 Calibration** (p. 17)
 - **1.5 Statistics** (p. 18)
 - **1.5.1 Distributions** (p. 18)
 - **1.5.2 Statistical Estimations** (p. 21)
 - **1.5.3 Hypothesis Testing** (p. 22)
 - **1.6 Lifelong Learning** (p. 25)
 - **1.7 Problems** (p. 26)
 - **2.1.1 Current** (p. 28)
- **1.8 References** (p. 27)
- **2 Basic Concepts of Electronics** (p. 28)
 - **2.1 Electronic Components and Circuit Analysis** (p. 28)
 - **2.1.2 Voltage and Potential** (p. 30)
 - **2.1.3 Resistors and Ohm's Law** (p. 30)
 - **2.1.4 Basic Circuit Analysis** (p. 34)
 - **2.1.5 Attenuators** (p. 38)
 - **2.1.6 Common Electrical Instruments** (p. 40)
 - **2.1.7 Capacitors** (p. 43)
 - **2.1.8 Inductors** (p. 45)
 - **2.1.9 First-Order Systems** (p. 47)
 - **2.1.10 Frequency** (p. 50)
 - **2.1.11 Series and Parallel Impedances** (p. 55)
 - **2.1.12 Electrical Safety** (p. 56)
 - **2.2.3 Inverter** (p. 58)
 - **2.2 Amplifiers** (p. 56)
 - **2.2.1 Basic Op Amp** (p. 57)
 - **2.2.2 Ideal Op Amp** (p. 57)

- **2.2.4 Noninverting Amplifier** (p. 59)
- **2.2.5 Differential Amplifiers** (p. 61)
- **2.2.6 Comparators** (p. 63)
- **2.2.7 Frequency Response** (p. 64)
- **2.3 Filters** (p. 65)
 - **2.3.1 Input-Output Relationship of Filters** (p. 66)
 - **2.3.2 Low-pass Filter** (p. 67)
 - **2.3.3 High-Pass Filter** (p. 68)
 - **2.3.4 Other Filters** (p. 69)
 - **2.3.5 Timers** (p. 70)
- **2.4 Analog-to-Digital (ADC) and Digital-to-Analog (DAC) Conversion** (p. 71)
 - **2.4.1 Number Systems** (p. 72)
 - **2.4.2 Digital-to-Analog Converters (DAC)** (p. 74)
 - **2.4.3 Analog-to-Digital Converters (ADC)** (p. 76)
- **2.5 Digital Signal Processing** (p. 79)
 - **2.5.1 Digital Signals** (p. 79)
 - **2.5.2 Sampling Theorem** (p. 80)
- **2.6 Microcomputers** (p. 81)
 - **2.6.1 Structure of a Microcomputer** (p. 81)
 - **2.6.2 Microprocessor-Based Systems** (p. 83)
- **2.7 Software and Programming Languages** (p. 84)
 - **2.7.1 Operating System** (p. 85)
 - **2.7.2 Programming Languages** (p. 86)
 - **2.7.3 Algorithms** (p. 87)
 - **2.7.4 Database systems** (p. 87)
- **2.8 Display Devices** (p. 88)
- **2.9 Recording Devices** (p. 89)
- **2.10 Problems** (p. 90)
- **2.11 References** (p. 91)
- **3 Analysis of Molecules in Clinical Medicine** (p. 91)
 - **3.1 Spectrophotometry** (p. 91)
 - **3.1.1 Components** (p. 91)
 - **3.1.2 Theory** (p. 91)
 - **3.1.3 Calibration** (p. 95)
 - **3.1.4 Clinical Laboratory Tests** (p. 95)
 - **3.1.5 Microdialysis** (p. 95)
 - **3.2 Oxygen Saturation** (p. 96)
 - **3.3 Bilirubin** (p. 97)
 - **3.4 Lactate** (p. 98)
 - **3.5 Creatinine** (p. 98)
 - **3.6 Urea** (p. 99)
 - **3.7 Glucose** (p. 100)
 - **3.7.1 Glucose Oxidase Method** (p. 101)
 - **3.7.2 Hexokinase method** (p. 102)
 - **3.8 Amperometric Biosensors for Oxygen and Glucose** (p. 102)
 - **3.8.1 Oxygen (PO₂)** (p. 102)

- **3.8.2 Glucose** (p. 104)
- **3.9 Ion-selective Electrodes for pH and CO₂** (p. 106)
- **3.11.2 Ion Source** (p. 110)
- **3.10 Flame Photometry** (p. 108)
 - **3.10.1 Lithium** (p. 109)
 - **3.10.2 Sodium and Potassium** (p. 109)
- **3.11 Mass Spectrometry** (p. 109)
 - **3.11.1 Sample Inlet** (p. 110)
 - **3.11.3 Mass Analyzer** (p. 112)
 - **3.11.4 Detector** (p. 113)
- **3.12 Carbon Dioxide Concentration Measurement by Infrared Transmission Spectroscopy** (p. 113)
- **3.13 Nitrogen by Emission Spectrometry** (p. 114)
- **3.14 Drugs by Fluorometry and Chromatography** (p. 115)
 - **3.14.1 Fluorometry** (p. 115)
 - **3.14.2 Chromatography** (p. 117)
 - **3.14.3 Gas Chromatography** (p. 118)
 - **3.14.4 Liquid Chromatography** (p. 121)
 - **3.14.5 Ion Exchange Chromatography** (p. 121)
- **3.15 Electrophoresis** (p. 122)
 - **3.15.1 Components of an Electrophoretic System** (p. 122)
 - **3.15.2 Electrophoretic Mobility** (p. 124)
- **3.16 DNA Sequencing** (p. 125)
- **3.17 Problems** (p. 127)
- **4.1.1 Integrated Approach** (p. 130)
- **3.18 References** (p. 128)
- **4 Surface Characterization in Biomaterials and Tissue Engineering** (p. 129)
 - **4.1 Molecules and Biomaterials** (p. 129)
 - **4.1.2 Types of Biomaterials** (p. 130)
 - **4.1.3 Polymers** (p. 131)
 - **4.2 Molecules and Tissue Engineering** (p. 134)
 - **4.2.1 Tissue Engineering** (p. 134)
 - **4.2.2 Cellular Composites** (p. 134)
 - **4.3 Surface Analysis** (p. 135)
 - **4.3.1 Topography** (p. 136)
 - **4.3.2 Chemical Composition** (p. 147)
 - **4.3.3 Polymer-water Interface** (p. 158)
 - **4.4 Protein Adsorption** (p. 159)
 - **4.4.1 Protein Molecule** (p. 160)
 - **4.4.2 Protein Adsorption Fundamentals** (p. 161)
 - **4.4.3 Protein Adsorption Measurements** (p. 161)
 - **4.5 Molecular Size** (p. 163)
 - **4.6 Problems** (p. 166)
- **5.1.1 Components of Blood** (p. 171)
- **4.7 References** (p. 167)
- **5 Hematology** (p. 170)

- **5.1 Blood Components and Processing** (p. 170)
 - **5.1.2 Basic Techniques** (p. 171)
 - **5.1.3 Blood Collection** (p. 171)
 - **5.1.4 Centrifugal Method** (p. 173)
- **5.2 Red Blood Cells** (p. 174)
 - **5.2.1 Factors Affecting Red Blood Cell Count** (p. 175)
 - **5.2.2 Hematocrit** (p. 175)
 - **5.2.3 Hemoglobin** (p. 175)
 - **5.2.4 Red Blood Cell Indices** (p. 175)
 - **5.2.5 Red Blood Cell Count** (p. 176)
 - **5.2.6 Hemoglobin** (p. 182)
 - **5.2.7 Reticulocyte Count** (p. 183)
 - **5.2.8 Sickle Cell Test** (p. 184)
- **5.3 White Blood Cells** (p. 184)
 - **5.3.1 Differential White Blood Cell Counts** (p. 184)
- **5.4 Platelets** (p. 186)
 - **5.4.1 Phase Hemocytometer** (p. 186)
- **5.5 Complete Blood Count** (p. 188)
- **5.6 Problems** (p. 188)
- **5.7 References** (p. 189)
- **6 Cellular Measurements in Biomaterials and Tissue Engineering** (p. 190)
 - **6.1 Cell Measurement Overview** (p. 190)
 - **6.1.1 What Is a Cell?** (p. 190)
 - **6.1.2 Fixed Versus Live Cells** (p. 192)
 - **6.2 Light Microscopy** (p. 194)
 - **6.2.1 Resolution Versus Magnification** (p. 195)
 - **6.2.2 Light Microscope Modes** (p. 197)
 - **6.2.3 Electronic Microscopy** (p. 202)
 - **6.2.4 Cellular Markers** (p. 203)
 - **6.2.5 Confocal Laser Scanning Microscopy** (p. 207)
 - **6.2.6 Two-Photon Excitation Microscopy** (p. 208)
 - **6.3.2 Video enhanced contrast microscopy** (p. 211)
 - **6.2.7 Image Processing** (p. 209)
 - **6.3 Cell Orientation** (p. 210)
 - **6.3.1 Orientation Chamber** (p. 211)
 - **6.4 Cell-rolling Velocity** (p. 211)
 - **6.5 Cell Pore Size Determination** (p. 213)
 - **6.5.1 TEM** (p. 214)
 - **6.5.2 SEM** (p. 214)
 - **6.6 Cell Deformation** (p. 215)
 - **6.6.1 Micropipet Technique** (p. 215)
 - **6.6.2 Optical Trapping** (p. 215)
 - **6.7 Cell Shear Stress** (p. 216)
 - **6.7.1 Cone and Plate** (p. 216)
 - **6.7.2 Fluorescent Ratiometric Imaging** (p. 217)
 - **6.8 Cell Adhesion** (p. 218)

- **6.8.1 Laser Trap** (p. 218)
- **6.8.2 Interferometry** (p. 218)
- **6.8.3 SEM** (p. 218)
- **6.9 Cell Migration** (p. 219)
- **6.9.1 4-D Image Processing System** (p. 219)
- **6.10 Cell Uptake** (p. 219)
- **6.10.1 Nanovid Microscopy** (p. 219)
- **6.10.2 Electroporation** (p. 220)
- **6.11 Cell Protein Secretion** (p. 220)
- **6.11.1 Atomic Force Microscopy** (p. 220)
- **6.11.2 Fluorescence Lifetime Imaging** (p. 220)
- **6.11.3 Fluorescence Recovery after Photobleaching** (p. 221)
- **6.13 Cell Differentiation** (p. 223)
- **6.12 Cell Proliferation** (p. 222)
- **6.12.1 Radiation Monitoring** (p. 223)
- **6.12.2 Fluorescence Microscopy** (p. 223)
- **6.13.1 Fluorescence Ratio Imaging** (p. 224)
- **6.13.2 Cell Sorter** (p. 224)
- **6.14 Cell Signaling and Regulation** (p. 225)
- **6.14.1 Fluorescence In-Situ Hybridization (FISH)** (p. 225)
- **6.14.2 Radioactive Labeling** (p. 226)
- **6.15 Problems** (p. 227)
- **6.16 References** (p. 228)
- **7 Nervous System** (p. 228)
- **7.1 Cell Potential** (p. 229)
- **7.1.1 Resting Potential** (p. 229)
- **7.1.2 Action Potential** (p. 229)
- **7.2 Brain, EEG, and Evoked Potentials** (p. 230)
- **7.2.1 Anatomy and Function of the Brain** (p. 230)
- **7.2.2 Electroencephalography (EEG)** (p. 231)
- **7.2.3 Evoked Potentials** (p. 233)
- **7.3 Brain Imaging: X ray** (p. 237)
- **7.4 Brain Imaging: CT** (p. 238)
- **7.5 Brain Imaging: MRI** (p. 238)
- **7.6 Brain Imaging: Nuclear Imaging** (p. 239)
- **7.7 Brain Imaging: Single-Photon Emission Computed Tomography (SPECT)** (p. 241)
- **7.8 Brain Imaging: Positron Emission Tomography (PET)** (p. 241)
- **7.9 Brain Imaging: Biomagnetism** (p. 242)
- **7.10 Eye, ERG, EOG, and Visual Field** (p. 244)
- **7.10.1 Electroretinogram (ERG)** (p. 244)
- **7.10.2 Electro-Oculogram (EOG)** (p. 245)
- **7.10.3 Visual Field** (p. 246)
- **7.10.4 Eye Pressure** (p. 247)
- **7.10.5 Ophthalmoscopy** (p. 248)
- **7.11.3 Otoscopy** (p. 252)

- **7.11 Ears and Audiometry** (p. 250)
- **7.11.1 The Ears** (p. 250)
- **7.11.2 Audiometry** (p. 251)
- **7.12 Muscles** (p. 252)
- **7.12.1 Muscle Contraction, Length and Force** (p. 252)
- **7.12.2 Electromyography (EMG)** (p. 256)
- **7.12.3 Neuromuscular Performance** (p. 257)
- **7.13 Problems** (p. 258)
- **7.14 References** (p. 259)
- **8 Heart and Circulation** (p. 262)
- **8.1 Cardiac Anatomy and Physiology** (p. 262)
- **8.1.1 Heart Valves** (p. 263)
- **8.1.2 Cardiac Cycle** (p. 265)
- **8.1.3 Cardiac Excitation and Control** (p. 266)
- **8.2 Cardiac Biopotentials** (p. 267)
- **8.2.1 Electrodes** (p. 267)
- **8.2.2 Electrocardiogram** (p. 267)
- **8.2.3 Electrograms** (p. 273)
- **8.3 Cardiac Pressures** (p. 274)
- **8.3.1 Strain Gage** (p. 274)
- **8.3.2 Catheter** (p. 275)
- **8.4 Cardiac Output** (p. 276)
- **8.4.1 Fick Method** (p. 277)
- **8.4.2 Thermodilution** (p. 278)
- **8.4.3 Dye Dilution** (p. 279)
- **8.4.4 Radionuclide Angiography** (p. 280)
- **8.4.5 Echocardiography** (p. 280)
- **8.4.6 Magnetic Resonance Imaging (MRI)** (p. 283)
- **8.5 Cardiac Sounds** (p. 283)
- **8.5.1 Stethoscopes** (p. 284)
- **8.5.2 Microphones** (p. 284)
- **8.6 Myocardial Viability** (p. 286)
- **8.6.1 Positron Emission Tomography (PET)** (p. 286)
- **8.6.2 Thallium-201 Imaging** (p. 288)
- **8.6.3 Myocardial Contrast Echocardiography** (p. 288)
- **8.7 Circulation** (p. 288)
- **8.8 Blood Flow** (p. 289)
- **8.8.1 Dilution** (p. 290)
- **8.8.2 Electromagnetic Flowmeter** (p. 290)
- **8.8.3 Ultrasonic Flowmeter** (p. 292)
- **8.8.4 Laser-Doppler Flowmeter** (p. 292)
- **8.9 Blood Pressure** (p. 294)
- **8.9.1 Indirect Measurement** (p. 295)
- **8.9.2 Direct Measurement** (p. 297)
- **8.9.3 Arterial tonometry** (p. 297)
- **8.11 Vessel Volume Flow** (p. 298)

- **8.10 Vessel Distension** (p. 297)
- **8.10.1 Intravascular Ultrasound** (p. 298)
- **8.10.2 Angiography** (p. 298)
- **8.11.1 Flow Visualization** (p. 299)
- **8.11.2 Ultrasonic Sonography** (p. 299)
- **8.11.3 Video Microscopy** (p. 300)
- **8.12 Problems** (p. 300)
- **8.13 References** (p. 301)
- **9 Lung, Kidney, Bone, and Skin** (p. 303)
- **9.3 Pulmonary Flow** (p. 310)
- **9.1 Lung** (p. 304)
- **9.2 Pulmonary Volume** (p. 304)
- **9.2.1 Measurement of Pulmonary Volume** (p. 306)
- **9.3.1 Measurement of Pulmonary Flow** (p. 311)
- **9.4 Pulmonary Diffusion** (p. 312)
- **9.5 Pulmonary Airway Resistance** (p. 313)
- **9.6 Kidney** (p. 314)
- **9.7 Kidney Clearance** (p. 314)
- **9.7.1 Creatinine** (p. 314)
- **9.8 Kidney Imaging** (p. 315)
- **9.8.1 Pyelogram** (p. 315)
- **9.9 Hemodialysis** (p. 315)
- **9.10 Peritoneal Dialysis** (p. 318)
- **9.11 Kidney Function** (p. 321)
- **9.11.1 Extracellular Water by Impedance** (p. 321)
- **9.12 Bones and Joints** (p. 322)
- **9.12.1 Bone Mineral Density** (p. 322)
- **9.12.2 Stress and Strain** (p. 323)
- **9.12.3 Strain Gage** (p. 326)
- **9.12.4 LVDT** (p. 327)
- **9.12.5 Soft Tissue Strain** (p. 328)
- **9.12.6 Joint Friction** (p. 329)
- **9.12.7 Bone Position** (p. 330)
- **9.12.8 Bone Strain-Related Potentials** (p. 330)
- **9.13 Skin** (p. 331)
- **9.13.1 Water Loss** (p. 331)
- **9.13.2 Color** (p. 334)
- **9.14 Problems** (p. 336)
- **9.15 References** (p. 337)
- **10 Body Temperature, Heat, Fat, and Movement** (p. 339)
- **10.1 Regulation of Body Temperature** (p. 340)
- **10.2 Clinical Temperature Measurement** (p. 342)
- **10.2.1 Surface Temperature Measurement** (p. 342)
- **10.2.2 Core Temperature Measurement** (p. 343)
- **10.3 Measurement of Body Heat: Calorimetry** (p. 348)
- **10.3.1 Direct Calorimetry** (p. 348)

- **10.3.2 Indirect Calorimetry** (p. 352)
- **10.4 Measurement of Body Fat** (p. 361)
- **10.4.1 Direct Measurement of Body Fat** (p. 362)
- **10.4.2 Indirect Measurement of Body Fat** (p. 366)
- **10.5 Measurement of Body Movement** (p. 370)
- **10.5.1 Goniometers and Accelerometers** (p. 371)
- **10.5.2 Video and Optoelectronic Systems** (p. 372)
- **10.6 Problems** (p. 374)
- **10.7 References** (p. 375)
- **Index** (p. 376)