

CONTENTS



UNIVERSIDAD NACIONAL DE ENTRE RÍOS
FACULTAD DE INGENIERÍA
CENTRO DE MEDICINA
BIBLIOTECA

3920

1 THE HUMAN BODY: AN OVERVIEW 1

- 1.1 Objectives 1
- 1.2 Self-Evaluation Questions 1
- 1.3 Introduction 1
- 1.4 The Cell 2
- 1.5 Body Fluids 3
- 1.6 Musculoskeletal System 3
- 1.7 Respiratory System 3
- 1.8 Gastrointestinal System 3
- 1.9 Nervous System 6
- 1.10 Endocrine System 6
- 1.11 The Circulatory System 6
- 1.12 The Body as a Control System 6
- 1.13 Summary 8
- 1.14 Recapitulation 8
- Questions 8
- Suggested Reading 9

2 THE HEART AND CIRCULATORY SYSTEM 10

- 2.1 Objectives 10
- 2.2 Self-Evaluation Questions 10
- 2.3 The Circulatory System 10
- 2.4 The Heart 14
- 2.5 Bioelectricity 16

- 2.6 Electroconduction System of the Heart 17
- 2.7 Heart Problems 21
- 2.8 Summary 22
- 2.9 Recapitulation 23
- Questions 23
- Problems 24
- References 25

3 INTRODUCTION TO BIOMEDICAL INSTRUMENTATION AND MEASUREMENT 25

- 3.1 Objectives 25
- 3.2 Self-Evaluation Questions 25
- 3.3 Introduction 25
- 3.4 Significant Figures 27
- 3.5 Scientific Notation 29
- 3.6 Units and Physical Constants 29
- 3.7 What Is Average? 30
- 3.8 Logarithmic Representation of Signal Levels: Decibel Notation 35
- 3.9 The Basics of Measurement Theory 39
- 3.10 Summary 43
- 3.11 Recapitulation 44

Questions 44
 Problems 44
 Reference 45
 Suggested Readings 45

4 BASIC THEORIES OF MEASUREMENT 46

4.1 Objectives 46
 4.2 Self-Evaluation Questions 46
 4.3 Introduction 46
 4.4 Categories of Measurement 47
 4.5 Factors in Making Measurements 50
 4.6 Measurement Errors 54
 4.7 Categories of Error 54
 4.8 Dealing with Measurement Errors 57
 4.9 Error Contribution Analysis 58
 4.10 Operational Definitions in
 Measurement 58
 4.11 Summary 59
 4.12 Recapitulation 60
 Questions and problems 60

5 SIGNALS AND NOISE 62

5.1 Objectives 62
 5.2 Self-Evaluation Questions 62
 5.3 Types of Signals 62
 5.4 Fourier Series 63
 5.5 Waveform Symmetry 68
 5.6 Transient Signals 70
 5.7 Sampled Signals 71
 5.8 Noise 74
 5.9 Signal-to-Noise Ratio 75
 5.10 Noise Factor, Noise Figure, and
 Noise Temperature 77
 5.11 Noise in Cascade Amplifiers 78
 5.12 Noise Reduction Strategies 79
 5.13 Summary 81
 5.14 Recapitulation 81
 Questions 81
 Problems 82

6 ELECTRODES, SENSORS, AND TRANSDUCERS 84

6.1 Objectives 84
 6.2 Self-Evaluation Questions 84

6.3 Signal Acquisition 84
 6.4 Transduction 85
 6.5 Active versus Passive Sensors 85
 6.6 Sensor Error Sources 85
 6.7 Sensor Terminology 86
 6.8 Tactics and Signals Processing for
 Improved Sensing 92
 6.9 Electrodes for Biophysical
 Sensing 94
 6.10 Medical Surface Electrodes 100
 6.11 Microelectrodes 103
 6.12 Transducers and Other Sensors 106
 6.13 Strain Gauges 109
 6.14 Inductive Transducers 113
 6.15 Quartz Pressure Sensors 116
 6.16 Capacitive Transducer 117
 6.17 Temperature Transducers 119
 6.18 Matching Sensors to Circuits 121
 6.19 Summary 123
 6.20 Recapitulation 123
 Questions 123
 Problems 124
 Suggested Readings 125

7 BIOELECTRIC AMPLIFIERS 126

7.1 Objectives 126
 7.2 Self-Evaluation Questions 126
 7.3 Bioelectric Amplifiers 126
 7.4 Operational Amplifiers 128
 7.5 Basic Amplifier Configurations 130
 7.6 Multiple-Input Circuits 140
 7.7 Differential Amplifiers 141
 7.8 Signal Processing Circuits 152
 7.9 Practical Op-amps: Some Problems
 Reviewed 156
 7.10 Bioelectric Amplifiers Reviewed 158
 7.11 Isolation Amplifiers 158
 7.12 Chopper Stabilized Amplifiers 175
 7.13 Input Guarding 177
 7.14 Summary 190
 7.15 Recapitulation 192
 Questions 192
 Problems 194
 Suggested Reading 194
 Consensus Standards (not law) Referenced by
 Legal Organizations 195

8 ELECTROCARDIOGRAPHS 197

- 8.1 Objectives 197
- 8.2 Self-Evaluation Questions 197
- 8.3 The Heart as a Potential Source 197
- 8.4 The ECG Waveform 198
- 8.5 The Standard Lead System 198
- 8.6 Other ECG Signals 199
- 8.7 The ECG Preamplifier 201
- 8.8 ECG Readout Devices 219
- 8.9 ECG Machines 219
- 8.10 ECG Machine Maintenance 225
- 8.11 ECG Faults and Troubleshooting 226
- 8.12 Summary 229
- 8.13 Recapitulation 230
- Questions 230
- Problems 232
- Suggested Reading 232

9 PHYSIOLOGICAL PRESSURE AND OTHER CARDIOVASCULAR MEASUREMENTS AND DEVICES 234

- 9.1 Objectives 234
- 9.2 Self-Evaluation Questions 234
- 9.3 Physiological Pressures 234
- 9.4 What Is Pressure? 235
- 9.5 Pressure Measurements 236
- 9.6 Blood Pressure Measurements 238
- 9.7 Oscillometric and Ultrasonic Noninvasive Pressure Measurements 242
- 9.8 Direct Methods: H_2O Manometers 243
- 9.9 Pressure Transducers 246
- 9.10 Pressure Amplifiers 246
- 9.11 Typical Calibration Methods 248
- 9.12 Pressure Amplifier Designs 249
- 9.13 ac Carrier Amplifiers 254
- 9.14 Systolic, Diastolic, and Mean Detector Circuits 255
- 9.15 Pressure Differentiation (dP/dT) Circuits 258
- 9.16 Automatic Zero Circuits 258
- 9.17 Practical Problems in Pressure Monitoring 261
- 9.18 Step-Function Frequency Response Test 266

- 9.19 Transducer Care 268
- 9.20 Cardiac Output Measurement 269
- 9.21 Dilution Methods 270
- 9.22 Right-Side Heart Pressures 279
- 9.23 Plethysmography 278
- 9.24 Blood Flow Measurements 280
- 9.25 Phonocardiography 283
- 9.26 Vectorcardiography 286
- 9.27 Catheterization Laboratories 287
- 9.28 The Heart Revisited 287
- 9.29 Defibrillators 289
- 9.30 Defibrillator Circuits 293
- 9.31 Cardioversion 294
- 9.32 Testing Defibrillators 295
- 9.33 Pacemakers 296
- 9.34 Heart-Lung Machines 297
- 9.35 Summary 299
- 9.36 Recapitulation 300
- Questions 300
- Problems 303
- References 303

10 THE HUMAN RESPIRATORY SYSTEM AND ITS MEASUREMENT 305

- 10.1 Objectives 305
- 10.2 Self-Evaluation Questions 305
- 10.3 The Human Respiratory System 306
- 10.4 Gas Laws 306
- 10.5 Internal (Cellular) Respiration 307
- 10.6 External (Lung) Respiration 308
- 10.7 Organs of Respiration 309
- 10.8 Mechanics of Breathing 311
- 10.9 Parameters of Respiration 312
- 10.10 Regulation of Respiration 315
- 10.11 Unbalanced and Diseased States 317
- 10.12 Environmental Threats to the Respiratory System 317
- 10.13 Major Measurements of Pulmonary Function 317
- 10.14 Respiratory System Measurements 318
- 10.15 Respiratory Transducers And Instruments 318
- 10.16 Spirometers 323
- 10.17 Pulmonary Measurement Systems and Instruments 325

- 10.18 Summary 236
- 10.19 Recapitulation 327
- Questions 327
- Problems 328
- Suggested Reading 329

11 RESPIRATORY THERAPY EQUIPMENT 330

- 11.1 Objectives 330
- 11.2 Self-Evaluation Questions 330
- 11.3 Disease States Requiring Artificial Respiratory Therapy 331
- 11.4 Overview and Terms of Ventilation 331
- 11.5 Historical Perspective of Artificial Respiratory Ventilation 332
- 11.6 Medical Gasses and Safety Systems 332
- 11.7 Oxygen Therapy 333
- 11.8 Intermittent Positive Pressure Breathing Therapy 336
- 11.9 Artificial Mechanical Ventilation 340
- 11.10 Accessory Devices Used in Respiratory Therapy Apparatus 343
- 11.11 Sterilization and Isolation Procedures In Respiratory Therapy Units 344
- 11.12 Typical Faults and Maintenance Procedures for Ventilators 344
- 11.13 Summary 345
- 11.14 Recapitulation 345
- Questions 346
- Problems 347
- Suggested Reading 347

12 THE HUMAN NERVOUS SYSTEM 349

- 12.1 Objectives 349
- 12.2 Self-Evaluation Questions 349
- 12.3 Organization of the Nervous System 350
- 12.4 The Neuron (Single Nerve Cell) 352
- 12.5 Structure and Function of the Central Nervous System 355
- 12.6 Peripheral Nervous System 362
- 12.7 Autonomic Nervous System 362

- 12.8 Behavior and the Nervous System 364
- 12.9 Summary 364
- 12.10 Recapitulation 365
- Questions 366
- Problems 366
- Suggested Reading 367

13 INSTRUMENTATION FOR MEASURING BRAIN FUNCTION 369

- 13.1 Objectives 369
- 13.2 Self-Evaluation Questions 369
- 13.3 Instrumentation for Measuring Anatomical and Physiological Parameters of the Brain 370
- 13.4 Cerebral Angiography 370
- 13.5 Cranial X-rays 370
- 13.6 Brain Scans 371
- 13.7 Ultrasonic Equipment 372
- 13.8 Electroencephalography 372
- 13.9 EEG Electrodes and the 10-20 System 374
- 13.10 EEG Amplitude and Frequency Bands 375
- 13.11 EEG Diagnostic Uses and Sleep Patterns 379
- 13.12 Multichannel EEG Recording Systems and Typical External Controls 380
- 13.13 The EEG System—Simplified Block Diagram 382
- 13.14 Preamplifiers and EEG System Specifications 382
- 13.15 Visual and Auditory Evoked Potential Recordings 387
- 13.16 EEG Telemetry System 388
- 13.17 Typical EEG System Artifacts, Faults, Troubleshooting, and Maintenance 388
- 13.18 Summary 392
- 13.19 Recapitulation 393
- Questions 393
- Problems 394
- Suggested Reading 395

14 INTENSIVE AND CORONARY CARE UNITS 396

- 14.1 Objectives 396
- 14.2 Self-Evaluation Questions 396
- 14.3 Special Care Units 396
- 14.4 ICU/CCU Equipment 397
- 14.5 Bedside Monitors 398
- 14.6 Bedside Monitor Circuits 400
- 14.7 Central Monitoring Consoles 406
- 14.8 ECG/Physiological Telemetry 411
- 14.9 Summary 420
- 14.10 Recapitulation 420
- Questions 420

15 OPERATING ROOMS 422

- 15.1 Objectives 422
- 15.2 Self-Evaluation Questions 422
- 15.3 Surgery 422
- 15.4 Types of Surgery 423
- 15.5 OR Personnel 423
- 15.6 Sterilization 424
- 15.7 OR Equipment 425
- 15.8 Summary 426
- 15.9 Recapitulation 426
- Questions 426

16 MEDICAL LABORATORY INSTRUMENTATION 427

- 16.1 Objectives 427
- 16.2 Self-Evaluation Questions 427
- 16.3 Blood (Purpose and Components) 428
- 16.4 Blood Tests (Cells and Chemistry) 430
- 16.5 Medical Laboratory Department 431
- 16.6 Overview of Clinical Instrumentation 431
- 16.7 Colorimeter 432
- 16.8 Flame Photometer 434
- 16.9 Spectrophotometer 435
- 16.10 Blood Cell Counters 436
- 16.11 pH/Blood Gas Analyzers 442
- 16.12 Chromatograph 445
- 16.13 Autoanalyzer 446
- 16.14 Basic Renal Physiology 449

- 16.15 Renal Failure 449
- 16.16 Peritoneal Dialysis 450
- 16.17 Hemodialysis 450
- 16.18 The Hemodialysis Machine 451
- 16.19 High-Flux and High Efficiency Dialysis 452
- 16.20 Electrical Safety Precautions 453
- 16.21 Typical Faults, Troubleshooting and Maintenance 453
- 16.22 Summary 454
- 16.23 Recapitulation 455
- Questions 455
- Problems 456
- Suggested Reading 457

17 MEDICAL ULTRASONOGRAPHY 458

- 17.1 Objectives 458
- 17.2 Self-Evaluation Questions 458
- 17.3 What Is Ultrasound? 458
- 17.4 Physics of Sound and Ultrasound Waves 459
- 17.5 Ultrasound Transducers 465
- 17.6 Absorption and Attenuation of Ultrasound Energy 468
- 17.7 Scan Modes and Scanning Systems 471
- 17.8 Biological Effects of Ultrasound 477
- 17.9 Doppler Effect 478
- 17.10 Transcutaneous Doppler Flow Detectors 479
- 17.11 Flowmeters 479
- 17.12 Ultrasonic Blood Pressure Measurement 483
- 17.13 Echoencephalography 485
- 17.14 Summary 487
- 17.15 Recapitulation 487
- Questions 487
- Problems 489
- Suggested Reading 489

18 ELECTROSURGERY GENERATORS 490

- 18.1 Objectives 490
- 18.2 Self-Evaluation Questions 490

- 18.3 Electrosurgery Machines 490
- 18.4 Electrosurgery Circuits 491
- 18.5 Electrosurgery Safety 494
- 18.6 Testing Electrosurgery Units 496
- 18.7 Summary 498
- 18.8 Recapitulation 498
- Questions 498
- Problems 498

19 CARE AND FEEDING OF BATTERY-OPERATED MEDICAL EQUIPMENT 499

- 19.1 Objectives 499
- 19.2 Self-Evaluation Questions 499
- 19.3 Introduction 499
- 19.4 Cells or Batteries? 500
- 19.5 Nickel Cadmium Cells and Batteries 500
- 19.6 Battery Capacity 500
- 19.7 Battery-Charging Protocols 501
- 19.8 NiCd Battery Memory 502
- 19.9 Battery Maintenance 502
- 19.10 Charging NiCd Batteries 503
- 19.11 Multiple-Cell Batteries 505
- 19.12 Other Batteries 505
- 19.13 Summary 508
- 19.14 Recapitulation 508
- Questions 508

20 WAVEFORM DISPLAY DEVICES 510

- 20.1 Objectives 510
- 20.2 Self-Evaluation Questions 510
- 20.3 Permanent Magnet Moving Coil Instruments 511
- 20.4 PMMC Writing System 511
- 20.5 Servorecorders and Recording Potentiometers 514
- 20.6 X-Y Recorders 517
- 20.7 Problems in Recorder Design 517
- 20.8 Maintenance of PMMC Writing Styluses and Pens 519
- 20.9 Dot Matrix Analog Recorders 521
- 20.10 Oscilloscopes 523
- 20.11 Medical Oscilloscopes 524
- 20.12 Multibeam Oscilloscopes 525

- 20.13 Nonfade Oscilloscopes 528
- 20.14 Modern Oscilloscope Designs 531
- 20.15 Summary 532
- 20.16 Recapitulation 532
- Questions 532
- Problems 533

21 ELECTRO-OPTICS (FIBER OPTICS AND LASERS) 534

- 21.1 Objectives 534
- 21.2 Self-Evaluation Questions 534
- 21.3 Fiber-Optic Technology 534
- 21.4 Fiber-Optic Isolation 535
- 21.5 History of Fiber Optics 536
- 21.6 Review of Some Basics 536
- 21.7 Fiber Optics 538
- 21.8 Intermodal Dispersion 539
- 21.9 Graded Index Fibers 541
- 21.10 Losses in Fiber-Optic Systems 541
- 21.11 Losses in Fiber-Optic Circuits 543
- 21.12 Fiber-Optic Communications Systems 545
- 21.13 Receiver Amplifier and Transmitter Driver Circuits 546
- 21.14 Lasers 548
- 21.15 Laser Classification 548
- 21.16 Basic Concepts 548
- 21.17 Types of Lasers 550
- 21.18 Driver Circuits for Solid-State Laser Diodes 554
- 21.19 Laser Diode Receiver Circuits 558
- 21.20 Summary 560
- 21.21 Recapitulation 560
- Questions 560
- Problems 561

22 COMPUTERS IN BIOMEDICAL EQUIPMENT 562

- 22.1 Objectives 562
- 22.2 Self-Evaluation Questions 562
- 22.3 Introduction 563
- 22.4 Computer Hardware and Software 565

22.5	Computer Programming Languages	567
22.6	Microprocessor and Microcomputer Systems	569
22.7	Interface Between Analog Signals and Digital Computers	571
22.8	Hardware, Software, and Firmware	573
22.9	Modern Communications	573
22.10	Modern Microprocessors	575
22.11	Microcontrollers	577
22.12	Digital Signal Processors	577
22.13	Capabilities of Microcomputers Versus Mainframes	578
22.14	The Power of Interactive Data Bases	578
22.15	Impact and Limitations of Computers	578
22.16	Computers Can Cause Health Problems	579
22.17	Computer Viruses	580
22.18	Supercomputers	580
22.19	Neural Networks and Computing Applications	580
22.20	The Internet	581
22.21	Internet and Medical Computer Information	582
22.22	PC, CD-ROM, and Interactive, Palmtop, and Laptop Computing and Health Care	583
22.23	Expert System	584
22.24	Computer-Based Patient Record	585
22.25	Computer Workstations	585
22.26	Computers in Laboratory Instrumentation	586
22.27	Brief Glossary of Computer and Laboratory Instrumentation Words	590
22.28	Computers in Medical Research	592
22.29	Computers in Biomedical Equipment	592
22.30	Summary	598
22.31	Recapitulation	600
	Questions	600
	Suggested Reading	601

23 RADIOLOGY AND NUCLEAR MEDICINE EQUIPMENT 607

23.1	Objectives	607
23.2	Self-Evaluation Questions	607
23.3	Types and Uses of X-ray and Nuclear Medicine Equipment	608
23.4	Origin and Nature of X-rays	610
23.5	Nature and Types of Nuclear Radiation	612
23.6	Units for Measuring Radioactivity	613
23.7	Health Dangers from X-ray and Nuclear Radiation	613
23.8	Generation of X-rays in an X-ray Tube	614
23.9	Block Diagram and Operation of an X-ray Machine	615
23.10	Block Diagram and Operation of a Fluoroscopic Machine	618
23.11	Block Diagram and Operation of a Nuclear Medicine System	619
23.12	Computer Systems Used in X-ray and Nuclear Medicine Equipment	621
23.13	Calibration, Typical Faults, Troubleshooting, and Maintenance Procedures	622
23.14	Summary	623
23.15	Recapitulation	624
	Questions	624
	Problems	624
	Suggested Reading	625

24 ELECTROMAGNETIC INTERFERENCE TO MEDICAL ELECTRONIC EQUIPMENT 626

24.1	Objectives	626
24.2	Self-Evaluation Questions	626
24.3	Introduction	626
24.4	Types and Sources of EMI	627
24.5	Fields	628
24.6	EMI Effects	629
24.7	Standards, Regulations, and Laws	630
24.8	EMI Mitigation	630

- 24.9 Intermodulation Problems 631
- 24.10 Dealing with TVI 636
- 24.11 Dealing with Signal Overload Problems 638
- 24.12 ECG Equipment and EMI 644
- 24.13 EMI to Biomedical Sensors 644
- 24.14 Summary 648
- 24.15 Recapitulation 648
- Questions 649
- Problems 649
- Suggested Reading 649

25 QUALITY ASSURANCE AND CONTINUOUS QUALITY IMPROVEMENT 651

- 25.1 Objectives 651
- 25.2 Self-Evaluation Questions 651
- 25.3 Introduction 651
- 25.4 The Theory of Variation 652
- 25.5 Variation in a System 652
- 25.6 Variation Throughout History 652
- 25.7 Variation 653
- 25.8 Types of Variation 653
- 25.9 Charting Variation 654
- 25.10 Creating a Histogram 654
- 25.11 Using Histograms in Quality Control 657
- 25.12 Interpreting QC Histograms 658
- 25.13 Control Charts 660
- 25.14 Analyzing Control Charts 661
- 25.15 Causes of Variation 662
- 25.16 Discriminating Between Special and Common Causes 662
- 25.17 Common Causes and Special Causes: Detection 663
- 25.18 Responses to Common and Special Causes 663
- 25.19 TQM, ISO-9000, and Six-Sigma 663
- 25.20 And the Benefits? 666
- 25.21 Summary 667
- 25.22 Recapitulation 667
- Questions 667
- Suggested Reading 667

26 MEDICAL EQUIPMENT MAINTENANCE: MANAGEMENT, FACILITIES, AND EQUIPMENT 668

- 26.1 Objectives 668
- 26.2 Self-Evaluation Questions 668
- 26.3 Introduction 668
- 26.4 Types of MROs 669
- 26.5 Levels of Capability 669
- 26.6 Types of Organization 671
- 26.7 Technical Personnel 674
- 26.8 Management Approaches 677
- 26.9 Summary 679
- 26.10 Recapitulation 679
- Questions 680
- Suggested Reading 680

27 REQUIREMENTS MANAGEMENT 681

- 27.1 Objectives 681
- 27.2 Self-Evaluation Questions 681
- 27.3 Introduction 681
- 27.4 Some Definitions 682
- 27.5 Why Are Requirements Important? 682
- 27.6 What Types of Requirements Are There? 684
- 27.7 Scope of Requirements 685
- 27.8 Symptoms of Bad Requirements 685
- 27.9 Primary and Derived Requirements 685
- 27.10 Functional and Nonfunctional Requirements 686
- 27.11 Stakeholder and System Requirements 686
- 27.12 Requirements Application 686
- 27.13 Compliance Level 686
- 27.14 Priority 686
- 27.15 Requirements Documents 686
- 27.16 What Are The Characteristics of Good Requirements? 687
- 27.17 How are Good Requirements Written? 689
- 27.18 Requirements Do Not Reflect Actual Needs of the User 689
- 27.19 Inconsistent Requirements 690

27.20	Incomplete Requirements	690
27.21	Conflicting Requirements	690
27.22	Misunderstood or Misinterpreted Requirements	690
27.23	Ambiguous Requirements	691
27.24	Vague Requirements	691
27.25	Introduced Requirements	691
27.26	Spurious Requirements	691
27.27	Unintended Consequences	691
27.28	Approaches to Requirements: Stakeholder Viewpoint	691
27.29	Elements of a Good Requirements Document	692
27.30	Wordsmithing	692
27.31	How Do You Manage Requirements?	693

27.32	Summary	693
27.33	Recapitulation	694
	Questions	694
	Suggested Readings	694

APPENDIX A: SOME MATH NOTES 696

A-1 Differentiation 696

A-2 Integration 697

APPENDIX B: MEDICAL TERMINOLOGY 699

APPENDIX C: GLOSSARY 702

APPENDIX D: ELECTRICAL SAFETY IN THE MEDICAL ENVIRONMENT 710

INDEX 731