Contents

Foreward

P	ret	fa	ce
-			••

XV

xvii

1

1 Materials in the Lab

1.1 Glass 1

- 1.1.1 Introduction. 1
- **1.1.2** Structural Properties of Glass, 1
- 1.1.3 Devitrification, 5
- 1.1.4 Different Types of Glass Used in the Lab, 6
- 1.1.5 Separating Glass by Type, 14
- 1.1.6 Physical Properties of Glass and Mechanisms of Glass Fracture, 17
- **1.1.7** Stress in Glass. **20**
- 1.1.8 Managing Thermal and Physical Stress in the Laboratory. 22
- 1.1.9 Tempered Glass. 24
- 1.1.10 Glass and Internal Pressure. 26
- 1.1.11 Limiting Broken Glass in the Lab. 28
- **1.1.12** Storing Glass, **30**
- 1.1.13 Marking Glass, 31
- 1.1.14 Consumer's Guide to Purchasing Laboratory Glassware. 32

1.2 Flexible Tubing 34

- 1.2.1 Introduction. 34
- 1.2.2 Physical Properties of Mexible Tubing, 35
- 1.2.3 Chemical Resistance Properties of Mexible Tubing. 37

1.3 Corks, Stoppers, and Enclosures 41

- 1.3.1 Corks. 41
- 1.3.2 Rubber Stoppers. 41

- 1.3.3 Pre-holed Stoppers, 42
- 1.3.4 Inserting Glass Tubing into Stoppers. 46
- 1.3.5 Removing Glass from Stoppers and Flexible Tubing. 47
- 1.3.6 Film Enclosures, 48

1.4 O-rings 49

- 1.4.1 O-rings in the Laboratory, 49
- 1.4.2 Chemical Resistance of O-ring Material, 49
- 1.4.3 O-ring Sizes, 49

References, 52

2 Measurement

2.1 Measurement: The Basics 53

- 2.1.1 Uniformity. Reliability. and Accuracy. 53
- 2.1.2 History of the Metric System, 54
- 2.1.3 The Base Units, 58
- 2.1.4 The Use of Prefixes in the Metric System, 63
- 2.1.5 Measurement Rules. 63

2.2 Length 66

- 2.2.1 The Ruler, 66
- 2.2.2 How to Measure Length. 66
- 2.2.3 The Caliper. 67
- 2.2.4 The Micrometer. 70

2.3 Volume 72

- 2.3.1 The Concepts of Volume Measurement, 72
- 2.3.2 Background of Volume Standards, 72
- 2.3.3 Categories, Markings, and Tolerances of Volumetric Ware, 74
- 2.3.4 Materials of Volumetric Construction #1 Plastic, 76
- 2.3.5 Materials of Volumetric Construction **#2** Glass, 77
- 2.3.6 Reading Volumetric Ware, 80
- 2.3.7 General Practices of Volumetric Ware Use, 81

- 2.3.8 Calibrations, Calibration, and Accuracy, 81
- 2.3.9 Correcting Volumetric Readings. 83
- 2.3.10 Volumetric Flasks, 87
- 2.3.11 Graduated Cylinders, 89
- 2.3.12 Pipettes. 91
- 2.3.13 Burettes, 97
- 2.3.14 Types of Burettes, 98
- 2.3.15 Care and Use of Burettes. 99
- 2.4 Weight and Mass 101
 - **2.4.1** Tools for Weighing. **10**1
 - 2.4.2 Weight vs. Mass vs. Density. 102
 - 2.4.3 Air Buoyancy, 102
 - 2.4.4 Accuracy. Precision. and Other Balance Limitations, 104
 - 2.4.5 Balance Location, 105
 - 2.4.6 Balance Reading. 107
 - 2.4.7 The Spring Balance. 109
 - 2.4.8 The Lever Arm Balance, 110
 - **2.4.9** Beam Balances. 112
 - 2.4.10 Analytical Balances, 113
 - 2.4.11 The Top-loading Balance, 117
 - 2.4.12 Balance Verification, 118
 - 2.4.13 Calibration Weights. 119
- 2.5 Temperature 123
 - 2.5.1 The Nature of Temperature Measurement. 123
 - 2.5.2 The Physics of Temperature-taking, 125
 - 2.5.3 Expansion-based Thermometers. 127
 - 2.5.4 Linear Expansion Thermometers. 128
 - 2.5.5 Volumetric Expansion Thermometers. 129
 - 2.5.6 Short- and Long-term Temperature Variations. 133
 - 2.5.7 Thermometer Calibration, 134
 - 2.5.8 Thermometer Lag. 135
 - 2.5.9 Air Bubbles in Liquid Columns, 135

2.5.10 Pressure Expansion Thermometers, 1372.5.11 Thermocouples, 1372.5.12 Resistance Thermometers, 143References, 145

3 Joints, Stopcocks, and Glass Tubing 147

3.1 Joints and Connections 147

- 3.1.1 Standard Taper Joints. 147
- 3.1.2 Ball-and-socket Joints. 151
- 3.1.3 The O-ring Joint. 152
- 3.1.4 Hybrids and Alternative Joints. 153
- 3.1.5 Special Connectors. 154
- 3.2 Stopcocks and Valves 156
 - 3.2.1 Glass Stopcocks. 156
 - 3.2.2 Teflon Stopcocks, 160
 - 3.2.3 Rotary Valves, 161
 - 3.2.4 Stopcock Design Variations. 163
- **3.3** Maintenance and Care of Joints, Stopcocks. and Glassware **164**
 - 3.3.1 Storage and Use of Stopcocks and Joints. 164
 - 3.3.2 Preparation for Use, 167
 - 3.3.3 Types of Greases, 168
 - 3.3.4 The Teflon Sleeve, 173
 - 3.3.5 Applying of Grease to Stopcocks and Joints, 173
 - 3.3.6 Preventing Glass Stopcocks and Joints from Sticking or Breaking on a Working System, 174
 - 3.3.7 Unsticking Joints and Stopcocks. 175
 - 3.3.8 Leaking Stopcocks and Joints. 177
 - 3.3.9 What To Do About Leaks in Stopcocks and Joints. 180
 - 3.3.10 General Tips. 181

- 3.4 Glass Tubing 181
 - 3.4.1 The Basics of Glass Tubing. 181
 - 3.4.2 Calculating the Inside Diameter (I.D.), 182
 - **3.4.3** Sample Volume Calculations. **183**

References, 196

4 Cleaning Glassware

- 4.1 The Clean Laboratory 197
 - 4.1.1 Basic Cleaning Concepts. 197
 - 4.1.2 Safety, 200
 - **4.1.3** Soap and Water, **201**
 - 4.1.4 Ultrasonic Cleaners. 203
 - 4.1.5 Organic Solvents, 204
 - **4.1.6** The Base Bath, **206**
 - 4.1.7 Acids and Oxidizers, 207
 - 4.1.8 Chromic Acid, 208
 - 4.1.9 Hydrofluoric Acid. 210
 - 4.1.10 Extra Cleaning Tips. 212
 - 4.1.11 Additional Cleaning Problems and Solutions. 213
 - 4.1.12 Last Resort Cleaning Solutions, 214

References, 215

5 Compressed Gases

- 5.1 Compressed Gas Tanks 217
 - 5.1.1 Types of Gases, 217
 - 5.1.2 The Dangers of Compressed Gas, 218
 - 5.1.3 CGA Fittings. 219
 - 5.1.4 Safety Aspects of Compressed Gas Tanks. 220
 - 5.1.5 Safety Practices Using Compressed Gases, 231
 - 5.1.6 In Case of Emergency, 234
 - 5.1.7 Gas Compatibility with Various Materials, 234

217

5.2 The Regulator 237

- 5.2.1 The Parts of the Regulator, 237
- 5.2.2 House Air Pressure System. 240
- 5.2.3 How to Install a Regulator on a Compressed Gas Tank. 240
- 5.2.4 How to Use Regulators Safely. 241
- 5.2.5 How to Test for Leaks in a Compressed Gas System, 242
- 5.2.6 How to Purchase a Regulator. 242

6 High & Low Temperature

245

6.1 High Temperature 245

- 6.1.1 The Dynamics of Heat in the Lab. 245
- 6.1.2 General Safety Precautions, 245
- 6.1.3 Open Flames. 246
- 6.1.4 Steam. 250
- 6.1.5 Thermal Radiation. 252
- **6.1.6** Hot Air Guns, 252
- 6.1.7 Electrical Resistance Heating. 253
- 6.1.8 Alternatives to Heat. 257

6.2 Low Temperature 258

- 6.2.1 The Dynamics of Cold in the Lab. 258
- 6.2.2 Room Temperature Tap Water (≈20°C), 258
- 6.2.3 Ice (0°C), 258
- 6.2.4 Ice With Salts (0°C to -96.3°C), 259
- 6.2.5 Dry Ice (Frozen Carbon Dioxide) (-78°C). 259
- 6.2.6 Liquid Nitrogen (-195.8°C), 259
- 6.2.7 Slush Baths (+13° to -160°C). 261
- 6.2.8 Safety With Slush Baths, 265
- 6.2.9 Containment of Cold Materials, 265
- 6.2.10 Liquid (Cryogenic)Gas Tanks. 268

References. 274

7 Vacuum Systems

7.1 How to Destroy a Vacuum System 275

7.2 An Overview of Vacuum Science and Technology 276

- 7.2.1 Preface. 276
- 7.2.2 How To Use a Vacuum System. 278
- 7.2.3 The History of Vacuum Equipment. 278
- 7.2.4 Pressure, Vacuum, and Force, 280
- 7.2.5 Gases, Vapors, and the Gas Laws , 281
- **7.2.6** Vapor Pressure, **283**
- 7.2.7 How to Make (and Maintain) a Vacuum, 284
- 7.2.8 Gas Flow, 287
- 7.2.9 Throughput and Pumping Speed, 290

7.3Pumps 291

- 7.3.1 The Purpose of Pumps. 291
- 7.3.2 The Aspirator, 293
- 7.3.3 Types and Features of Mechanical Pumps. 294
- 7.3.4 Connection. Use. Maintenance, and Safety, 294
- 7.3.5 Condensable Vapors. 303
- **7.3.6** Traps for Pumps, **305**
- 7.3.7 Mechanical Pump Oils, 306
- 7.3.8 Various Mechanical Pump Oils, 308
- 7.3.9 Storing Mechanical Pumps, 310
- 7.3.10 Limitations of Mechanical Pumps and the Demands of Highvacuum Pumps, 310
- 7.3.11 Diffusion Pumps, 311
- 7.3.12 Attaching a Diffusion Pump to a Vacuum System, 314
- 7.3.13 How to Use a Diffusion Pump. 316
- 7.3.14 Diffusion Pump Limitations. 320
- 7.3.15 Diffusion Pump Oils. 321
- 7.3.16 Diffusion Pump Maintenance. 323
- 7.3.17 Toepler Pumps, 327

7.4 Traps 328

- 7.4.1 The Purpose and Functions of Traps. 328
- 7.4.2 Types of Traps, 330
- 7.4.3 Proper Use of Cold Traps. 332
- 7.4.4 Cold Trap Maintenance, 335
- 7.4.5 Separation Traps, 338
- 7.4.6 Liquid Traps, 339
- 7.5 Vacuum Gauges 340
 - 7.5.1 The Purposes (and Limitations) of Vacuum Gauges. 340
 - 7.5.2 The Mechanical Gauge Family. 342
 - 7.5.3 Cleaning a Mechanical Gauge. 343
 - 7.5.4 The Liquid Gauge Family. 343
 - 7.5.5 The Manometer. 344
 - 7.5.6 The McLeod Gauge. 347
 - 7.5.7 How to Read a McLeod Gauge. 349
 - 7.5.8 Bringing a McLeod Gauge to Vacuum Conditions, 351
 - 7.5.9 Returning a McLeod Gauge to Atmospheric Conditions. 351
 - 7.5.10 The Tipping McLeod Gauge. 352
 - 7.5.11 Condensable Vapors and the McLeod Gauge, 353
 - 7.5.12 Mercury Contamination from McLeod Gauges. 354
 - 7.5.13 Cleaning a McLeod Gauge. 355
 - 7.5.14 Thermocouple and Pirani Gauges. 356
 - 7.5.15 The Pirani Gauge, 357
 - 7.5.16 Cleaning Pirani Gauges, 358
 - 7.5.17 The Thermocouple Gauge. 359
 - 7.5.18 Cleaning Thermocouple Gauges. 359
 - 7.5.19 The Ionization Gauge Family. 359
 - 7.5.20 The Hot-cathode Ion Gauge. 361
 - 7.5.21 Cleaning Hot-cathode Ion Gauges, 365
 - 7.5.22 The Cold-cathode Ion Gauge. 365
 - 7.5.23 Cleaning Cold-cathode Ion Gauges, 367
 - 7.5.24 The Momentum Transfer Gauge (MTG), 367

Contents

- 7.6 Leak Detection and Location 367
 - 7.6.1 Is Poor Vacuum a Leak or a Poor Vacuum?, 367
 - 7.6.2 False Leaks. 368
 - 7.6.3 Real Leaks. 370
 - 7.6.4 Isolation to Find Leaks. 376
 - 7.6.5 Probe Gases and Liquids. 378
 - 7.6.6 The Tesla Coil. 380
 - 7.6.7 Soap Bubbles. 384
 - 7.6.8 Pirani or Thermocouple Gauges. 385
 - 7.6.9 Helium Leak Detection. 386
 - 7.6.10 Helium Leak Detection Techniques. 389
 - 7.6.11 General Tips and Tricks of Helium Leak Detection. 392

7.6.12 Repairing Leaks. 399

7.7 More Vacuum System Information 400

7.7.1 Designing a Vacuum System. 400References. 405

8 The Gas-oxygen Torch

- 8.1 The Gas-oxygen Torch 409
 - 8.1.1 Types of Gas-oxygen Torches. 409
 - 8.1.2 How to Light a Gas-oxygen Torch, 412
 - 8.1.3 How to Prevent a Premix Torch from Popping. 413
- 8.2 Using the Gas-oxygenTorch 414
 - 8.2.1 Uses for the Gas-oxygen Torch in the Lab. 414
 - 8.2.2 How to Tip Off A Sample, 414
 - 8.2.3 How to Nre-polish the End of a Glass Tube, 419
 - 8.2.4 Brazing and Silver Soldering. 420

421

Appendices

- A Preparing Drawings for the Glass Shop 421
 - A.1 Common Problems with Drawings to Glass Shops. 421
 - A.2 Drawing Recommendations, 422
- B Polymer Resistance 424
 - B.1 Introduction, 424
 - B.2 Polyolefins, 425
 - **B.3** Engineering Resins, **426**
 - B.4 Fluorocarbons, 427
 - **B.4** Chemical Resistance Chart, **428**
- C Manufacturers 434
- D Recommended Reading 440

Index