

## **Contents**

<b>Foreward</b>	<b>xv</b>
<b>Preface</b>	<b>xvii</b>
<b>1 Materials in the Lab</b>	<b>1</b>
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 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	
1.1.15 Introduction, 34	
1.1.16 Physical Properties of Flexible Tubing, 35	
1.1.17 Chemical Resistance Properties of Flexible Tubing, 37	
1.3 Corks, Stoppers, and Enclosures 41	
1.1.18 Corks, 41	
1.1.19 Rubber Stoppers, 41	
1.1.20 Pre-holed Stoppers, 42	
1.1.21 Inserting Glass Tubing into Stoppers, 46	
1.1.22 Removing Glass from Stoppers and Flexible Tubing, 47	
1.3.6 Film Enclosures, 48	

## 1.4 O-rings 49

1.1.23 O-rings in the Laboratory, 49

1.1.24 Chemical Resistance of O-ring Material, 49

1.1.25 O-ring Sizes, 49

References, 52

## 2 Measurement

53

### 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, 101
  - 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

## 2.3 Temperature 123

- 2.4.14 The Nature of Temperature Measurement, 123
- 2.4.15 The Physics of Temperature-taking, 125
- 2.4.16 Expansion-based Thermometers, 127
- 2.4.17 Linear Expansion Thermometers, 128
- 2.4.18 Volumetric Expansion Thermometers, 129
- 2.4.19 Short- and Long-term Temperature Variations, 133
- 2.4.20 Thermometer Calibration, 134
- 2.4.21 Thermometer Lag, 135
- 2.4.22 Air Bubbles in Liquid Columns, 135
- 2.4.23 Pressure Expansion Thermometers, 137
- 2.4.24 Thermocouples, 137
- 2.4.25 Resistance Thermometers, 143
- References, 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**

**197**

- 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**

**217**

### 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

### 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 ( $\sim 20^\circ\text{C}$ ), 258
- 6.2.3 Ice ( $0^\circ\text{C}$ ), 258
- 6.2.4 Ice With Salts ( $0^\circ\text{C}$  to  $-96.3^\circ\text{C}$ ), 259
- 6.2.5 Dry Ice (Frozen Carbon Dioxide) ( $-78^\circ\text{C}$ ), 259
- 6.2.6 Liquid Nitrogen ( $-195.8^\circ\text{C}$ ), 259
- 6.2.7 Slush Baths ( $+13^\circ\text{C}$  to  $-160^\circ\text{C}$ ), 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 275**

- 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
- 7.3 Pumps 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 Pumps Oils, 306
  - 7.3.8 Various Mechanical Pumps Oils, 308
  - 7.3.9 Storing Mechanical Pumps, 310
  - 7.3.10 Limitations of Mechanical Pumps and the Demands of High-Vacuum 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 Gauges, 361
- 7.5.21 Cleaning Hot-cathode Ion Gauges, 365
- 7.5.22 The Cold-cathode Ion Gauges, 365
- 7.5.23 Cleaning Cold-cathode Ion Gauges, 367
- 7.5.24 The Momentum Transfer Gauge (MTG), 367

## 7.6 Leak Detection and Location 367

- 7.5.25 Is Poor Vacuum a Leak or a Poor Vacuum?, 367
- 7.5.26 False Leaks, 368
- 7.5.27 Real Leaks, 370
- 7.5.28 Isolation to Find Leaks, 376
- 7.5.29 Probe Gases and Liquids, 378
- 7.5.30 The Tesla Coil, 380
- 7.5.31 Soap Bubbles, 384
- 7.5.32 Pirani or Thermocouple Gages, 385
- 7.5.33 Helium Leak Detection, 386
- 7.5.34 Helium Leak Detection Techniques, 389
- 7.5.35 General Tips and Tricks of Helium Leak Detection, 392

7.5.36	Repairing Leaks,	399	
7.7	More Vacuum System Information	400	
7.7.1	Designing a Vacuum System,	400	
	References,	405	
<b>8</b>	<b>The Gas-oxygen Torch</b>		<b>409</b>
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-oxygen Torch	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 Fire-polish the End of a Glass Tube,	419	
8.2.4	Brazing and Silver Soldering,	420	
	<b>Appendices</b>		<b>421</b>
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.5	Chemical Resistance Chart,	428	
C	Manufacturers	434	
D	Recommended Reading	440	
	<b>Index</b>		<b>445</b>