

Welding

Principles and Applications

Fifth Edition



Welding

Principles and Applications

Fifth Edition

Larry Jeffus





Welding Principles and Applications
Fifth Edition
Larry Jeffus

Business Unit Director:
Alar Elken

Executive Editor:
Sandy Clark

Acquisitions Editor:
Sanjeev Rao

Developmental Editor:
Alison S. Weintraub

Executive Marketing Manager:
Maura Theriault

Channel Manager:
Fair Huntoon

Marketing Coordinator:
Sarena Douglass

Executive Production Manager:
Mary Ellen Black

Project Editor:
Barbara L. Diaz

Senior Art/Design Coordinator:
Mary Beth Vought

Production Coordinator:
Sharon Popson

Editorial Assistant:
Jill Carnahan

COPYRIGHT 2004 by Delmar Learning, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Cover: Courtesy Hornell, Inc.
Section Opener Photos 1–5 and 7. Courtesy of Larry Jeffus
Section Opener Photo 6. Courtesy of Messer Eutectic

Printed in the United States of America
1 2 3 4 5 XX 06 05 04 03 02

For more information contact
Delmar Learning
Executive Woods
5 Maxwell Drive, P.O. Box 8007,
Clifton Park, NY 12065-8007
Or find us on the World Wide
Web at
<http://www.delmarlearning.com>

ALL RIGHTS RESERVED. Certain portions of this work © 1999, 1993, and 1988. No part of this work covered by the copyright hereon may be reproduced in any form or by any means—graphic, electronic, or mechanical, including photocopying, recording, taping, Web distribution, or information storage and retrieval systems—without the written permission of the publisher.

For permission to use material from the text or product, contact us by
Tel. (800) 730-2214
Fax (800) 730-2215
www.thomsonrights.com

Library of Congress Cataloging-in-Publication Data:

Jeffus, Larry F.
Welding: principles and applications/
Larry Jeffus.—5th ed. p. cm.
Includes index.
ISBN 1-40181-046-2
1. Welding. I. Title.

TS227 .J418 2003
671.5'2—dc21 2002031518

NOTICE TO THE READER

Publisher does not warrant or guarantee any of the products described herein or perform any independent analysis in connection with any of the product information contained herein. Publisher does not assume, and expressly disclaims, any obligation to obtain and include information other than that provided to it by the manufacturer.

The reader is expressly warned to consider and adopt all safety precautions that might be indicated by the activities herein and to avoid all potential hazards. By following the instructions contained herein, the reader willingly assumes all risks in connection with such instructions.

The publisher makes no representation or warranties of any kind, including but not limited to, the warranties of fitness for particular purpose or merchantability, nor are any such representations implied with respect to the material set forth herein, and the publisher takes no responsibility with respect to such material. The publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or part, from the readers' use of, or reliance upon, this material.

Contents

Preface	xi
Features of the Text	xiv
Acknowledgments	xvi
About the Author	xvii
Index of Experiments and Practices	xviii



SECTION 1 INTRODUCTION

Chapter 1 Introduction to Welding

Introduction	4
Welding Defined	5
Uses of Welding	6
Welding Processes	8
Occupational Opportunities in Welding	12
Training for Welding Occupations	14
Experiments and Practices	14
Welding Video Series	16
Metric Units	16
Welding at the Bottom of the World	19
Review	21

Chapter 2 Safety in Welding

Introduction	22
Burns	23
Eye and Ear Protection	24
Respiratory Protection	28
Ventilation	30
Material Specification Data Sheets (MSDS)	30
Waste Material Disposal	30
Electrical Safety	31
General Work Clothing	31
Special Protective Clothing	33
Handling and Storing Cylinders	34
Fire Protection	36
Equipment Maintenance	38
Work Area	38
Hand Tools	38
Power Tools	39
Metal Cutting Machines	40
Material Handling	41
Summary	42
Heads Up on Safety: Use Proper Head and Eye Protection	43
Review	45



SECTION 2 SHIELDED METAL ARC WELDING

Chapter 3 Shielded Metal Arc Equipment, Setup, and Operation

Introduction	48
Welding Current	49
Types of Welding Power	51
Open Circuit Voltage	52
Operating Voltage	52
Arc Blow	52
Types of Power Sources	53
Generators and Alternators	56
Rectifiers	57
Duty Cycle	58
Welding Cables	59
Electrode Holders	60
Work Clamps	61
Setup	61
Summary	62
Experienced Welders Make a Difficult Offshore Weld Run Smoothly	63
Review	64

Chapter 4 Shielded Metal Arc Welding of Plate

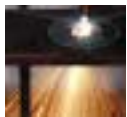
Introduction	65
Effect of Too High or Too Low Current Settings	67
Electrode Size and Heat	69
Arc Length	69
Electrode Angle	70
Electrode Manipulation	73
Positioning of the Welder and the Plate	75
Practice Welds	75
Stringer Beads	76
Square Butt Joint	78
Edge Weld	81
Outside Corner Joint	86
Lap Joint	89
Tee Joint	93
Summary	96
Keeping Shipshape through Underwater Welding	96
Review	99

Chapter 5 Shielded Metal Arc Welding of Pipe

Introduction.....	100
Pipe and Tubing.....	101
Preparation and Fitup.....	105
Practice Welds.....	106
1G Horizontal Rolled Position.....	110
2G Vertical Fixed Position.....	113
5G Horizontal Fixed Position.....	115
6G 45° Inclined Position.....	117
Summary.....	118
Orbital Welding Helps NASA's X-34 Rocket Soar.....	119
Review.....	120

Chapter 6 Advanced Shielded Metal Arc Welding

Introduction.....	121
Root Pass.....	122
Hot Pass.....	127
Filler Pass.....	129
Cover Pass.....	131
Plate Preparation.....	132
Preparing Specimens for Testing.....	134
Restarting a Weld Bead.....	135
Preheating and Postheating.....	135
Poor Fit.....	143
Summary.....	145
Artists Honored at International Institute of Welding (IIW) Assembly.....	145
Review.....	147

**SECTION 3
CUTTING AND GOUGING****Chapter 7 Flame Cutting**

Introduction.....	150
Metals Cut by the Oxyfuel Process.....	151
Eye Protection for Flame Cutting.....	151
Cutting Torches.....	151
Cutting Tips.....	153
Oxyfuel Cutting, Setup, and Operation.....	157
Hand Cutting.....	159
Layout.....	163
Selecting the Correct Tip and Setting the Pressure.....	163
The Chemistry of a Cut.....	165
The Physics of a Cut.....	166
Plate Cutting.....	168
Cutting Table.....	168
Torch Guides.....	169
Distortion.....	170
Cutting Applications.....	172
Pipe Cutting.....	173
Summary.....	175

Oxygen Cutting.....	176
Review.....	177

Chapter 8 Plasma Arc Cutting

Introduction.....	178
Plasma.....	179
Arc Plasma.....	179
Plasma Torch.....	180
Power and Gas Cables.....	182
Power Requirements.....	183
Heat Input.....	184
Distortion.....	184
Applications.....	185
Gases.....	189
Machine Cutting.....	190
Manual Cutting.....	191
Plasma Arc Gouging.....	191
Safety.....	191
Summary.....	196
Weld Shop Keeps U.S. Coast Guard Ready.....	197
Review.....	199

Chapter 9 Related Cutting Processes

Introduction.....	200
Laser Beam Cutting (LBC) and Laser Beam Drilling (LBD).....	201
Lasers.....	201
Applications.....	203
Laser Beam Cutting.....	203
Laser Beam Drilling.....	204
Laser Equipment.....	204
Air Carbon Arc Cutting.....	204
Manual Torch Design.....	205
Safety.....	208
Oxygen Lance Cutting.....	211
Applications.....	211
Water Jet Cutting.....	212
Applications.....	212
Summary.....	213
Lasers: The New Wave in Ship Construction.....	213
Review.....	215

**SECTION 4
GAS SHIELDED WELDING****Chapter 10 Gas Metal Arc Welding Equipment, Setup, and Operation**

Introduction.....	218
Metal Transfer.....	220
Filler Metal Specifications.....	225
Wire Melting and Deposition Rates.....	225
Welding Power Supplies.....	225
Molten Weld Pool Control.....	228

Equipment	231	Summary	332
Spot Welding	236	Welding Lends Architectural Flair to Airport Expansion	332
Summary	239	Review	334
Simple Steps to Achieving Better Gas Metal Arc Welding	239		
Review	241		
Chapter 11 Gas Metal Arc Welding		Chapter 14 Other Constant-potential Welding Processes	
Introduction	242	Introduction	335
Setup	242	Submerged Arc Welding (SAW)	336
Gas Density and Flow Rates	248	Weld Travel	336
Arc-voltage and Amperage Characteristics	249	Electrode Feed	336
Electrode Extension	251	Contact Tip	336
Welding Gun Angle	252	Electrode	336
Effect of Shielding Gas on Welding	253	Flux	337
Practices	255	Advantages of SAW	338
Metal Preparation	256	Disadvantages of SAW	339
Flat Position, 1G and 1F Positions	256	Arc Starting	339
Vertical Up 3G and 3F Positions	260	Weld Backing	339
Vertical Down 3G and 3F Positions	262	Hand-held SAW	339
Horizontal 2G and 2F Positions	264	Experiments	340
Overhead 4G and 4F Positions	265	Electroslag Welding (ESW)	340
Pulsed-arc Metal Transfer, 1G Position	267	Electrogas Welding (EGW)	342
Axial Spray	270	Summary	343
Summary	271	High-performance Steel Increasingly Used for Bridge Building	344
Aluminum Ferries Rely on Inverter Technology	272	Review	346
Review	274		
Chapter 12 Flux Cored Arc Welding Equipment, Setup, and Operation		Chapter 15 Gas Tungsten Arc Welding Equipment, Setup, Operation, and Filler Metals	
Introduction	275	Introduction	347
Principles of Operation	276	Types of Tungsten	350
Equipment	278	Shaping the Tungsten	351
Advantages	279	GTA Welding Equipment	354
Limitations	279	Types of Welding Current	358
Electrodes	280	Shielding Gases	360
Flux	281	Remote Controls	362
Shielding Gas	285	Summary	367
Welding Techniques	286	Welding a Pathway to the Stars	367
Summary	290	Review	370
Ultrasonic Plastics Welding Basics	291		
Review	293	Chapter 16 Gas Tungsten Arc Welding of Plate	
Chapter 13 Flux Cored Arc Welding		Introduction	371
Introduction	294	Torch Angle	372
Practices	295	Filler Rod Manipulation	372
Flat-position Welds	299	Tungsten Contamination	373
Square-groove Welds	300	Current Setting	374
V-groove and Bevel-groove Welds	301	Experiments	374
Fillet Welds	308	Gas Flow	375
Vertical Welds	313	Practice Welds	377
Horizontal Welds	318	Summary	399
Overhead-position Welds	323	The Great Master's Horse Returns Home after 500 Years	399
Thin-gauge Welding	326	Review	402

Chapter 17 Gas Tungsten Arc Welding of Pipe

Introduction.....	403
Practices.....	404
Joint Preparation.....	404
Root	405
Backing Gas	407
Filler Metal.....	408
Hot Pass	412
Filler Pass.....	415
Cover Pass.....	416
Summary.....	422
Hot Tap Weld Prevents Offshore Piping System from Shutting Down	423
Review.....	424



SECTION 5 RELATED PROCESSES

Chapter 18 Welding Joint Design, Welding Symbols, and Fabrication

Introduction.....	428
Weld Joint Design.....	429
Mechanical Drawings.....	434
Welding Symbols.....	439
Indicating Types of Welds.....	439
Weld Location.....	440
Location Significance of Arrow.....	441
Fillet Welds.....	441
Plug Welds.....	442
Spot Welds.....	443
Seam Welds.....	443
Groove Welds	443
Backing	446
Flanged Welds	446
Nondestructive Testing Symbols	448
Fabrication.....	448
Layout.....	454
Material Shapes.....	460
Assembly.....	464
Assembly Tools.....	465
Fitting	467
Tack Welding.....	467
Welding	468
Finishing.....	469
Summary.....	471
Metal Cored Welding Wire Comes through on Heavy Weldments	471
Review.....	473

Chapter 19 Welding Codes, Standards, and Costs

Introduction.....	475
Codes, Standards, Procedures, and Specifications.....	476
Welding Procedure Qualification	477
General Information	480

Welding Costs.....	489
Summary.....	506
Resistance Seam Welding Benefits Stainless Application.....	506
Review.....	508

Chapter 20 Testing and Inspection of Welds

Introduction.....	509
Quality Control.....	510
Discontinuities and Defects	510
Destructive Testing.....	516
Nondestructive Testing.....	525
Summary.....	534
Development of Titanium Inspection Tools Based on Weld Color	534
Review.....	537

Chapter 21 Welder Certification

Introduction.....	538
Qualified and Certified Welders	538
AWS Entry-level Welder Qualification and Welder Certification	539
Welding Skill Development.....	547
Welder Qualification and Certification Test Instructions for Practices	548
Layout, Assembly, and Fabrication of Weldments	554
Performance Qualification Test Record.....	582
Summary.....	583
Welder Certification: Many Thrusts, Few Agree.....	583
Review.....	585

Chapter 22 Railroad Welding

Introduction.....	587
Rail Types	588
Continuous Welded Track	591
Rail Repairs.....	591
Gouging.....	594
Cracks.....	594
Rail Ends.....	595
Arc Welding (AW).....	595
Flash Welding (FW).....	597
Thermite Welding (TW).....	597
Summary.....	600
Challenges of Starting Your Own Welding Shop	601
Review.....	603



SECTION 6 RELATED PROCESSES AND TECHNOLOGY

Chapter 23 Welding Metallurgy

Introduction.....	606
Heat, Temperature, and Energy.....	607

Hydrogen	754
Filler Metals	756
Mild Steel	757
Summary	758
Welding with the Right Shielding Gas	758
Review	759

Chapter 30 Oxyacetylene Welding

Introduction	760
Mild Steel Welds	760
Outside Corner Joint	768
Butt Joint	769
Lap Joint	772
Tee Joint	774
Out-of-position Welding	776
Vertical Welds	776
Butt Joint	777
Lap Joint	778
Tee Joint	779
Horizontal Welds	780
Horizontal Stringer Bead	780
Butt Joint	780
Lap Joint	781
Tee Joint	781
Overhead Welds	781
Stringer Bead	781
Mild Steel Pipe and Tubing	782
Horizontal Rolled Position 1G	783
Horizontal Fixed Position 5G	785
Vertical Fixed Position 2G	786
45° Fixed Position 6G	787
Thin-wall Tubing	788
Summary	788
Confined Space Monitors: Tough Choices for Tight Spots	789
Review	791

Chapter 31 Soldering, Brazing, and Braze Welding

Introduction	792
Advantages of Soldering and Brazing	793
Physical Properties of the Joint	795
Fluxes	796
Soldering and Brazing Methods	798
Filler Metals	801
Joint Design	806
Building Up Surfaces and Filling Holes	814
Silver Brazing	815
Soldering	819
Summary	822
Active Solder Joining of Metals, Ceramics, and Composites	823
Review	824

Appendix

I. Student Welding Report	826
II. Conversion of Decimal Inches to Millimeters and Fractional Inches to Decimal Inches and Millimeters	827
III. Conversion Factors: U.S. Customary (Standard) Units and Metric Units (SI)	828
IV. Abbreviations and Symbols	830
V. Metric Conversions Approximations	831
VI. Pressure Conversion	831
VII. Welding Codes and Specifications	832
VIII. Welding Associations and Organizations	833

Glossary875

Index881

Preface

Introduction

The welding industry today presents a continually growing and changing series of opportunities for skilled welders. Even with economic fluctuations, there is a positive job outlook in welding. Due to a steady growth in the demand for goods fabricated by welding, new welders are needed in every area of welding such as small shops, specialty fabrication shops, and large industries. The student who is preparing for a career in welding will need to

- have excellent eye-hand coordination
- work well with tools and equipment
- know the theory and application of the various welding and cutting processes
- be able to follow written and verbal instructions
- work with or without close supervision
- have effective written and verbal communication skills
- be able to resolve basic mathematical problems
- work well individually and in groups
- read and interpret welding drawings and sketches
- be able to operate a computer and use software programs
- be alert to possible problems to be able to work safely

A thorough study of *Welding: Principles and Applications* in a classroom/shop setting will help students prepare for the opportunities in modern welding technology. The comprehensive technical content provides the basis for the welding processes. The extensive descriptions of equipment and supplies, with in-depth explanations of their operation and function, familiarize students with the tools of the trade. The process descriptions, practices, and experiments coupled with actual performance teach the critical fabrication and welding skills required on the job. The text also discusses occupational opportunities in welding and explains the training required for certain welding occupations. The skills and personal traits recommended by the American Welding Society for their Certified Welder program are included within the text. Students wishing to become certified under the AWS program must contact the American Welding Society for specific details.

Organization

The text is organized to guide the student's learning from an introduction to welding, through critical safety information, to details of specific welding processes, and on to the related areas of welding metallurgy, weldability of metals, fabrication, certification, testing and inspection of welds, and welding joint design, costs, and welding symbols.

Each section of the text introducing a welding process or processes begins with an introduction to the equipment and materials to be used in the process(es), including setup in preparation for welding. The remaining chapters for the specific process concentrate on the actual welding techniques in various applications and positions. The content progresses from basic concepts to the more complex welding technology. Once this technology is understood, the student is able to quickly master new welding tasks or processes.

The welding processes in the text are presented in a manner that allows the student to begin with any section. It is not necessary to learn all of the processes if only one or two are required of your job.

Each chapter begins with a list of *learning objectives* that tell the student and instructor what is to be learned while studying the chapter. A survey of the objectives will show that the student will have the opportunity to develop a full range of welding skills, depending upon the topics selected for the program. Each major process is presented in such a way that the instructor can eliminate processes having little economic value in the market served by the program. However, the student will still learn all essential information needed for a thorough understanding of all processes studied.

In each chapter, *Key Terms* are **highlighted in color** and defined. In addition, the new terms are listed at the beginning of the chapter to enable students to recognize the terms when they appear. Terms and definitions used throughout the text are based on the American Welding Society's standards. Industry jargon has also been included where appropriate. The *Bilingual Glossary* includes a Spanish equivalent for each term, and many definitions feature additional drawings to assist all learners in gaining a complete understanding of the new term.

Cautions for the student are given throughout the text. *Metric equivalents* are listed in parentheses for dimensions. The metric equivalent in most cases has been rounded to the nearest whole number. Numerous full-color photographs, line drawings, and plans illustrate concepts and clarify the discussions.

Most of the chapters contain learning activities in the form of *Experiments* and *Practices*. The end of the experiments are identified by the (♦) and the end of the practices are identified by the (◆) symbol.

By completing the *Experiments*, the student learns the parameters of each welding process. Often, because it is hard both to perform the experiment and to observe the results closely, students will do most of the experiments in a small group. This will allow students both to perform the activity and to observe the reactions. In the experiments, the student changes the parameters to observe the effect on the process. In this way, the student learns to manipulate the variables to obtain the desired welding outcome for given conditions. The experiments provided in the chapters do not have right or wrong answers. They are designed to allow the student to learn the operating limitations or the effects of changes that may occur during the welding process.

A large selection of *Practices* are included to enable the student to develop the required manipulative skills, using different materials and material thicknesses in different positions. A sufficient number of practices is provided so that, after the basics are learned, the student may choose an area of specialization. Materials specified in the practices may be varied in both thickness and length to accommodate those supplies that students have in their lab. Changes within a limited range of both

thickness and length will not affect the learning process designed for the practice. A chapter-end summary recaps the significant material covered in the chapter. This summary will help the student more completely understand the chapter material and will serve as a handy study tool.

The *Review* questions at the end of each chapter can be used as indicators of how well the student has learned the material in each chapter.

Computers in Welding

As in every skilled trade in today's ever changing world, computers are becoming more commonly used in welding. Some of the basic programs provide a cross-reference to welding filler metals, whereas others aid in weld symbol selection. More complex programs allow welding engineers to design structures and test them for strength without ever building them. These programs aid in proper design and make more effective use of materials, resulting in better, more cost-effective construction. The most commonly used programs are ones such as Arc Works™, published by Lincoln Electric Company, which are used to help write Welding Procedure Specifications (WPS), Procedure Qualification Records (PQR), and Welder Qualification Test Records (WQTR). These documents are extensively used throughout the welding industry.

Most of the welding programs operate on a variety of platforms, but the most popular ones use a version of Microsoft Windows. Having a good basic understanding of the Windows operating platform will give you a great start with these programs. In addition you should become familiar with one of the commonly used word processing programs, such as Microsoft Word. This will aid you in producing high-quality reports both in school and later on the job.

Revision

The fifth edition of *Welding: Principles and Applications* has been thoroughly revised and reorganized to reflect the latest welding technologies.

In this edition there are all-new, full-color photos and detailed colored line art. The unique photographs in this book were taken from the welder's viewpoint. Approximately one-third of the photos were taken from a left-handed view to aid the left-handed students. The use of quality graphics make it much easier for the student to see what is expected to produce a quality weld.

The *Success Story* vignettes of real welders have been updated to provide motivation to students considering welding as a career. *Real World Features* have been expanded and appear in every chapter.

Supplements

Accompanying the text are an *Instructor's Guide*, a *Study Guide/Lab Manual*, and a videotape series showing in detail many of the setups and welding practices. Throughout the text are figures with a *Video Frame* around them. These are skills that are demonstrated in the video series. Chapters that contain *Video Frame* references are noted on the section openers.

The *Instructor's Guide* contains lesson plan outlines for each chapter. Transparency masters have also been included to assist in the classroom. Answers to the questions in the textbook and the *Study Guide/Lab Manual* are also included, along with additional questions and answers for testing. Certification information is also provided in the *Instructor's Guide*, including samples of typical certification tests from certifying agencies. Supplementary references will direct the instructor to additional sources of information for specific content areas.

The *Study Guide/Lab Manual* (ISBN 1-4018-1048-9) has been updated to reflect the changes made in this edition. The *Study Guide/Lab Manual* is designed to test student understanding of the concepts presented in the text. Each chapter starts with a review of the important topics dis-

cussed in the text. Students can then test their knowledge by answering additional questions. Lab exercises are included in those chapters (as appropriate) to reinforce the primary objectives of the lesson. Artwork and safety precautions are included throughout the manual.

Video series on Flux Cored Arc Welding (ISBN 0-7668-2292-3), Gas Metal Arc Welding (ISBN 0-7668-2299-0), Oxyacetylene Welding (ISBN 0-7668-2306-7), Shielded Metal Arc Welding (ISBN 0-7668-2313-X) and Gas Tungsten Arc Welding (ISBN 0-8064-1592-4) are also available to enhance the presentation of these topics. *Video Frames* throughout the text indicate that more material is available on one of the tape series, and each set is a four-part video series that shows the fundamentals of the process. Program activity sheets based on the videos and some CD-ROM versions of the series are also available.

The *Online Companion* is a free weblink to motivate students to learn more about professional opportunities in the welding workforce. It contains material and links about careers in welding, as well as a selection of video clips, so students can see welders in action, while learning about welding processes. Visit the *Online Companion* at www.delmarlearning.com/welding/jeffus.

FEATURES OF THE TEXT

Chapter 27

Other Welding Processes

OBJECTIVES

After completing this chapter, the student should be able to

- explain the operating principles for the different special welding processes.
- list the reasons that a particular process should be selected to make a special weld.
- list the operational limitations of each special welding process explained in this chapter.

KEY TERMS

electrical resistance
electron beam welding (EBW)
evacuated (vacuum) chamber
flash welding (FW)
hardfacing
inert gas welding
laser welding (LBW)
optical viewing system
percussion welding (PEW)
plasma-arc welding (PAW)
resistance welding (RW)
stud welding (SW)
thermal spraying (THSP)
ultrasonic welding (USW)
upset welding (UW)

INTRODUCTION

More than eighty different welding and allied processes are listed by the American Welding Society. This text covers nine of the most commonly used processes that require the welder to have a special skill. This chapter covers seventeen additional processes that call for special equipment and techniques. Some of these processes require less skill or knowledge to set up and operate, such as resistance spot welding (RSW). Others demand a great deal of technical information and training, such as electron beam welding (EBW). The actual operating procedures vary greatly from one manufacturer's machine to another. The specific settings also change from one material to another. Because of these factors, only the general theory, procedures, and applications are discussed in this chapter. More information can be obtained from the AWS or directly from the manufacturer of the equipment being operated. The skill needed to operate this equipment can be learned quickly on the job or in classes taught by the specific equipment manufacturer.

Objectives, found at the beginning of each chapter, are a brief list of the most important topics to study in the chapter.

Key terms are the most important technical words you will learn in the chapter. These are listed at the beginning of each chapter following the objectives and appear in color print where they are first defined. These terms are also defined in the glossary at the end of the book.

Cautions summarize critical safety rules. They alert you to operations that could hurt you or someone else. Not only are they covered in the safety chapter, but you will find them throughout the text when they apply to the discussion, practice, or experiment.

774 Section 7 Oxyfuel

Application	Acetylene	MAPP® Gas	Propylene
Cutting			
Under 1/8 in. thick	100	95	90
5/8 in. to 5 in. thick	95	100	95
Over 5 in. thick	80	100	95
Cutting dirty or scaled surfaces	100	95	80
Repetitive cutting	100	100	80
Stack cutting	90	100	95
Cutting low alloy specialty steels	100	90	80
Bleeding	100	100	85
Cutting rounds	95	100	85
Piercing	100	100	85
Blind-hole piercing	100	90	80
Rivet washing	100	95	80
Gouging	100	100	85
Wire metallizing	80	100	90
Powder metallizing	100	0	0
Heating, stress relief, bending	70	100	90
Deep flame hardening	90	100	90
Shallow flame hardening	95	100	80
Cobalt-base hardfacing	100	0	0
Other alloy hardfacing	100	85	70
Welding	100	70	0
Brace welding	100	90	70
Brazing	100	100	90

TABLE 29-6 Average Performance Ratings of Some Oxyfuel Flames. Courtesy of BOC Gases.

is that both gases consume a large amount of oxygen. Propane requires 85% of the flame's oxygen from the cylinder, and natural gas requires 95% of its oxygen from the cylinder, compared with an oxygen consumption of as little as 50% for the oxyacetylene flame.

Hydrogen

Oxyhydrogen produces only a primary combustion flame, unlike hydrocarbon gases, which have both primary and secondary combustion. The hydrogen flame is almost colorless and can be seen only when dirt, dust, and other contaminants from the air glow while burning in the flame. Hydrogen is not widely used in welding because of its expense, its limited availability, and some myths about its safety.

Hydrogen has the fastest burning velocity of any of the fuel gases at 36 ft/s (10.9 m/s). Acetylene has a burn rate of less than one-half that of hydrogen. Hydrogen has a very slight tendency to backfire, yet it does not flashback. Unlike acetylene, which can explosively decompose without oxygen, hydrogen cannot be made to react without the presence of sufficient oxygen.

Hydrogen is much lighter than air. Therefore, when it is released, it diffuses quickly, reducing the possibility of accidental combustion. If a large quantity of hydrogen is allowed to burn uncontrolled, the gas rises into the flame. This means it burns in an upward direction, away from people in an area. Most other gases burn in a downward direction, which can trap people in an area. The chance of large quantities of hydrogen exploding is limited. For example, when the hydrogen-filled airship,

the *Hindenburg*, caught fire and burned in 1931, no explosion occurred, and most of the people on board the airship survived.

The low-flame temperature restricts the use of the oxyhydrogen flame to cutting, usually underwater, and to gas welding and brazing on low-temperature metals such as aluminum. The flame can be made reducing (reducing oxygen) to help protect the aluminum from oxidation, without having excessive carbon to contaminate the weld. The finished flame product is water, H₂O. Only one-quarter of the flame oxygen comes from the cylinder.

Two major safety problems exist when hydrogen is used as a fuel gas. First, hydrogen has no smell, which makes it difficult to detect leaks. Second, the molecule is extremely small so that it leaks easily. When using hydrogen, an active leak-checking schedule must be followed to find small problems before they develop into disasters. It is possible for a leak to be on fire and not be noticed, because the hydrogen flame is almost invisible.

EXPERIMENT 29-2

Oxyfuel Flames

Using an identical torch set with each available fuel gas, you are going to observe the flame as each fuel gas is safely lit, adjusted, and extinguished.

Set all fuel and oxygen regulators at approximately 5 psig (35 kPa-g). Each torch should have the same-size tip. The tip should have an orifice equal to a number 53 to 60 drill. Place the torches on a table with the tips pointed up. Figure 29-20.

Chapter 28 Oxyfuel Welding and Cutting Equipment, Setup, and Operation 775

VIDEO

FIGURE 28-40 Cracking the oxygen and fuel cylinder valves to blow out any dirt lodged in the valves. Courtesy of Larry Jiffels. © Cengage Learning, 2012. Video series.

- Attach the regulators to the cylinder valves. Figure 28-42A. The nuts can be started by hand and then tightened with a wrench, Figure 28-42B.
- Attach a reverse flow valve or flashback arrestor, if the torch does not have them built in, to the hose connection on the regulator or to the hose connection on the torch body, depending on the type of reverse flow valve in the set. Figure 28-43. Occasionally test each reverse flow valve by blowing through it to make sure it works properly.
- Connect the hoses. The red hose has a left-hand grooved nut and attaches to the fuel-gas regulator. The green hose has a right-hand nut without grooves and attaches to the oxygen regulator.
- Attach the torch to the hoses, Figure 28-44. Connect both hose nuts fingertight before using a wrench to tighten either one.
- Check the tip seals for nicks or O-rings. If used, for damage. In most cases, tips that have O-rings-type seals are hand tightened, and tips that have metal-to-metal seals are wrench tightened, but it is best to check the owner's manual, or a supplier, to determine if the torch tip should be tightened, Figure 28-45.

FIGURE 28-41 Nonadjustable wrenches for acetylene cylinders. (A) Small Combination Wrench, (B) Large Combination Wrench, (C) T-Wrench. Courtesy of ESAB Welding & Cutting Products.

CAUTION
Tightening a tip the incorrect way may be dangerous and might damage the equipment.

Check all connections to be sure they are tight. The oxyfuel equipment is now assembled and ready for use. Complete a copy of the "Student Welding Report" listed in Appendix 1 or provided by your instructor.

PRACTICE 28-2
Turning On and Testing a Torch

Using the oxyfuel equipment that was properly assembled in Practice 28-1, a nonadjustable tank wrench, and a leak-detecting solution, you will pressurize the system and test for leaks.

- Back out the regulator pressure adjusting screws until they are loose, Figure 28-46.

Practices are hands-on exercises designed to build your welding skills. Each practice describes in detail what skill you will learn and what equipment, supplies, and tools you will need to complete the exercise.

Experiments are designed to allow you to see what effect changes in the process settings, operation, or techniques have on the type of weld produced. Many are group activities and will help you learn as a team.

Summaries review the important points in the chapter and serve as a useful study tool.

Real-world features at the ends of all chapters present a story that describes a real-world application of the theory learned in the chapter. You will see how particular knowledge and skills are important to the world.

824 Section 7 Oxyfuel

In electronic and electrical applications, metals, ceramics, semiconductors, and metal matrix composites (MMCs) need to be joined. Research on active solders showed a capability to join this range of electronic materials, using essentially the same active soldering process used in other metal joining.

Active solders have been able to wet, join, and even metallurgically interact with various structural and conductor metals, including aluminum, copper, titanium, stainless steel, nickel alloys, magnesium alloys, and refractory metals.

Applications in the consumer market that involve the joining of aluminum, stainless steel, copper, and titanium range from cooking utensils to sports equipment. There is also an increased use of materials such as carbides and diamond. Pots and pans are fabricated from aluminum or copper due to the high thermal conductivity of these metals. Aluminum and/or copper joining to stainless steel has been done by brazing, but it is difficult because of the differing oxide films, which must be removed by chemical fluxes. Zinc-based active solders have the potential to meet such needs in housewares. Golf and tennis equipment increasingly use titanium that could benefit from soldering fabrication. Additionally, joints of dissimilar or composite materials are often required for new golf club designs, which incorporate carbides and even diamonds for club faces. High-density refractory metals such as tungsten have also been added to modify swing stability. Active solders have the potential, and are being considered for, such joining needs.

Consumer Applications

Applications include satellite electronics, power devices, radiation shields, avionics, computers, microwave/radar, and power interconnections.

Typically, such packages use metallic materials for good thermal conductivity but then need to have electrically insulating materials joined to them.

Applications

The advantages and capabilities of active solder technology enable it to be considered for a wide range of applications. Active solder alloys can join many materials, including all metals, most ceramics, metal matrix composites, glasses, carbon (graphite/diamond), and ceramic.

Active solders provide metallic, thermally and electrically conductive joints that are tough but have sufficient ductility to effectively join many dissimilar material combinations. Its low-temperature joining, compared to brazing (for example, in joining aluminum alloys, metal-to-glass, or ceramic joints), offers advantages when joining mismatched materials.

Electronic Packaging

Electronic packages contain electronic devices and require material combinations that manage thermal and electrical conductivity while having low thermal expansion.

Art, photo, and article courtesy of the American Welding Society.

Review

1. Explain the difference between brazing and soldering.
2. How does capillary action separate brazing?
3. Why can brazing be both a permanent and a temporary joining method?
4. Why is it less likely that a semiskilled worker would damage a part with brazing than with welding?
5. What is the effect of joint spacing on joint tensile strength?
6. Why are braze joints subject to fatigue failure?
7. Do all braze joints resist corrosion? Give an example.
8. What are the three primary functions that a flux must perform?
9. In what forms are fluxes available?
10. How can liquid fluxes be delivered to the joint through the torch?
11. How do fluxes react with the base metal?
12. How are soldering and brazing methods grouped?
13. What are the advantages of torch soldering?
14. What are the advantages of furnace brazing?
15. How does the induction brazing method heat the part being brazed?
16. What soldering process can be used to join parts and provide a protective coating to the part at the same time?
17. What soldering or brazing process uses a machine similar to a spot welder to produce the heat required to make a joint?

Success stories are found at the beginning of each of the seven sections in the text. These stories are about real people who have become successful by using their welding skills. Each story is different, but one message is repeated by all story contributors: welding can be a rich and rewarding career.

Bilingual glossary definitions provide a Spanish equivalent for each new term. Additional line art in the glossary will also help you gain a greater understanding of challenging terms.

778 Section 7 Oxyfuel

Summary

In many applications, such as home and farm work, the oxyacetylene welding process is by far the most desirable because of its flexibility, portability, and cost. These factors will keep this process in the forefront of welding for the foreseeable future.

The wide variety of fuel gases available for oxyfuel welding, cutting, and brazing has offered the welder some unique challenges in determining the most appropriate fuel gas for their processes. Although acetylene and oxygen are the most common, acetylene is not always the most appropriate gas for a number of reasons, primarily cost. When treated properly the waste product from acetylene production has little or no environmental impact, but such treatments can be expensive. This significantly increases the cost of acetylene and has made other fuel gases more desirable. Other fuel gases do not have all of the characteristics of acetylene. Each gas has unique advantages and disadvantages. You must look at the advantages and disadvantages of all the gases before selecting the fuel gas that will be most appropriate for your applications.

Filler metal selection for the oxyfuel welding processes used in a home hobby application is not often given much thought. In industrial applications the proper selection of an oxyfuel filler metal is critical to the success of your product.

Welding with the Right Shielding Gas

Quality and consistency are key to any quality assurance program. You must be confident your processes are consistent and repeatable and that the products being used in production meet specific requirements and specifications.

To maintain a stable, consistent welding process and ensure repeatable results, you should implement a welding specification (WPS). A WPS gives the welder or welding operator the recipe for producing acceptable welds on a given application, time after time. In developing a WPS for gas metal arc or gas tungsten arc welding, many variables must be taken into account, such as voltage, amperage, electrode extension, and shielding gas. These and other variables are called "essential variables" as defined in AWS D1.1, Structural Welding Code—Steel.

The Classification System

With respect to shielding gases, AWS D1.1 states that a procedure qualification record (PQR) requires requalification when there is "a change in shielding gas from a single gas to any other single gas or mixture of gases, or in the specified nominal percentage composition of a gas mixture, or to no gas." Therefore, it is essential that your shielding gas composition be accurate and consistent to ensure WPSs are being followed and the desired weld quality is maintained.

It is the responsibility of your gas supplier to ensure you receive an accurate, consistent shielding gas supply that conforms to AWS A5.32, Specification for Welding Shielding Gases. AWS A5.32 sets the standards for the classification of shielding gases, similar to the way AWS 5.18, Specification for Carbon Steel Electrodes and Rods for Gas Metal Arc Welding, prescribes a classification system for identifying carbon steel electrodes and rods.



The label on your gas cylinders should state whether your supplier is complying with the AWS specification on shielding gases.

Review questions help measure the skills and knowledge you learned in the chapter. Each question is designed to help you apply and understand the information in the chapter.

Success STORY

When award-winning Navy welder SW1 Moses E. Sampson, Jr., was deployed to Po-Hang, South Korea, to assist in building headquarters facilities, he faced plenty of challenges—a language barrier, unfamiliar equipment, and lots of welding outdoors in near-zero temperatures. "But our team worked together to overcome those challenges," says Sampson. Now his toughest welding assignment has turned into his biggest accomplishment—two troop-processing facilities in South Korea, ready for the United States to defend South Korea—or itself—against North Korea. "We hope the buildings never come into play, but if they do, we can feel proud that we contributed," says Sampson.

Thirteen years in the Navy as a steelworker has taught Sampson a lot about the importance of his welding jobs. From welding assignments all over Europe, Asia, the Middle East, and Central America, Sampson has seen first-hand how much quality, consistency, and teamwork matter, especially during Operations Desert Storm and Desert Shield. "Welding is not a dead-end job," explains Sampson. "It's important to somebody else's life."

As a high-school senior in Summerville, South Carolina, Sampson did not have that kind of focus. "The area I grew up in didn't have anything to offer as far as jobs, and I wanted to do some traveling and learn a trade," says Sampson. He joined the Navy when he graduated, at age seventeen.

But Sampson knew right off the bat that he did not like ships, so he researched all the skills the Navy taught and discovered that CB Units, the construction units that house the welders. By to their assignments, stay for six months, and move on. "Plus welders make pretty good money after leaving the military," says Sampson. Learning to weld was tough but rewarding, and last year Sampson knew he had finally made his mark when he was selected to teach recruits. Some have outside welding experience; others are completely new to the trade, just as Sampson was.

"I think welding is exciting, and it's a privilege to teach," says Sampson. "When you're done, you have something you can see, something you've created with your own hands." And Sampson knows how hard it is to be a welding student trying to learn to be consistent. "Welding is nothing but patience and motivation," Sampson explains. "If you've got that drive, you can be a perfect welder—because practice makes perfect." 



Acknowledgments

To bring a book of this size to publication requires the assistance of many individuals, and the author and publisher would like to thank the following for their unique contributions to this and/or prior editions:

- John L. Chastain, who worked with the author for many long hours to perfect the photographic techniques required to achieve the action photos
- Larry Maupin for his effort and determination in producing many of the welding photographs in this text
- Dewayne Roy, Welding Department chairman at Mountain View College, Dallas Texas, for his many contributions to this text
- Special thanks are due to the following companies for their contributions to the text: Skills USA-VICA, Praxair, NASA Media Research Center, Miller Electric Co., Caterpillar, Inc., ESAB Welding & Cutting Products, Frommelt Safety Products, Hornell Speedglas, Inc., Mine Safety Appliances, Co., Lincoln Electric, Jackson Products/Thermadyne, Thermadyne Holdings, Hobart Brothers Co., Concoa Controls Corp., Stanley Works, Rexarc, Magnaflux Corp., Buehler Ltd., T. J. Snow Co., Inc., Victor Equipment, E.O. Paton Electric Welding Institute, CRC-Evans Automatic Welding, Cherry Point Refinery, The Aluminum Assoc./Automotive & Light Truck Group, E. I. DuPont de Nemours & Co., Philips Gmbh, Technical Systems, GWS Welding Supply Co., Merrick Engineering, Inc., Reynolds Metals Co., Liquid Air Corp., Alphagaz Div., American Torch Tip, ARC Machines, Inc., FANUX Robotics North America, Inc., Alexander Binzel Corp., Sciaky Brothers, Inc., Aluminum Co. of America, National Machine Co., Leybold Heraeus Vacuum Systems, Inc., Sonobond Ultrasonics, Foster Instruments, and The Prince & Izant Company

- The American Welding Society, Inc., whose *Welding Journal* was an invaluable source of many of the special-interest articles
- The following individuals, who reviewed the fourth edition in anticipation of the fifth. Their recommendations have been invaluable to the author:
Russ Carpenter, Northwest Technical Institute, Springdale, AR; Jon Cookson, Paul D. Camp Community College, Franklin, VA; Clay Corey; John Didziulis; Ben Eisley, Mount San Antonio College, Walnut, CA; William Heins, Northampton Community College, Bethlehem, PA; Paula Kmetz; John R. Penaz, Dunwoody Institute, Minneapolis, MN; Paul H. Plourde, New Hampshire Community Technical College, Manchester, NH; Kenneth Setzer; Stuart Strader; Clackamas Community College, Oregon City, OR; Leonard Valaitis, Wilkes-Barre Area Vocational-Technical School, Wilkes-Barre, PA
- The following individuals, who are featured in the Success Stories in the text and Online Companion; they are valuable contributors to the textbook and an inspiration for those entering the welding industry:
Kevin Aucompaugh; Caroline Gatten; Brian Muenchau; Moses E. Sampson, Jr.; Charles Sarcia; David Schnalzer; Jonathan Yount; and Randy Zajic

The author also would like to express his deepest appreciation to:

- Tina Ivey, Marilyn Burris, and Bernice Nolan for all the hours spent helping in the preparation of this edition
- Kristi Webb; Sam Burris; Ben Burris; Jordan Ivey; Hunter Ivey; Jennie Rothenberg; and his daughters, Wendy and Amy, for all of the general office help they provided
- His wife, Carol, for all of her moral support

**This book is dedicated to
two very special people, my
daughters Wendy and Amy.**



About the Author

During my junior year of high school, I learned to weld in metal shop. There I was taught basic welding principles and applications, and I was able to build a number of projects in shop using oxyacetylene welding, shielded metal arc welding, and brazing.

The practice welds helped me develop welding skills, and building the projects allowed me to start developing some fabrication skills. By the end of my junior year, I had become a fairly skilled welder.

In my sophomore year I joined the Vocational Industrial Clubs of America (VICA), now SkillsUSA-VICA. SkillsUSA brings together educators, administrators, corporate America, labor organizations, trade associations, and government in a coordinated effort to address America's need for a globally competitive, skilled workforce. The mission of SkillsUSA is to help our students become world-class workers and responsible American citizens. Through my involvement in SkillsUSA, I learned a great deal about industry and business. I learned in SkillsUSA the value of integrity, responsibility, citizenship, service, and respect. In addition, I developed leadership skills, established goals, and learned the value of performing quality work. These are all things that I still use in my life today.

In my senior year at New Bern High School, I was given an opportunity to join Mr. Z.T. Koonce's first class in a new program called Industrial Cooperative Training (ICT). ICT is a cooperative work experience program that coordinates school experiences with real jobs. This allowed me to attend high school in the morning, where I completed my required English, math, and other academic courses for graduation. We were also taught skills that would help us get a job—such as how to fill out a

job application, how to interview, and so on. In the afternoons I worked as a welder. After graduation I started a full-time job as a welder at Barbour Boat Works. There my welding skills were refined, and I was allowed to work with the other welders in the shipyard. My first welding assignment was on a barge, making intermittent welds to attach the deck to the barge's ribs.

As my welding skills improved, my supervisor allowed me to apply my new welding skills to more difficult jobs. I welded on barges, military landing crafts, tugboats, PT boats, small tankers, and others. This is how I earned money toward my college education.

With my welding skills, I was able to get a job in a small welding shop in Madisonville, Tennessee, and attended Hiwassee Junior College. After graduating from Hiwassee, I found other welding jobs that allowed me to continue my education at the University of Tennessee, where I earned a bachelor's degree. After four years, I had both a college degree and four years of industrial experience, which together qualified me for my job as a vocational teacher.

During my career as a welder, I have welded on tanks, pressure vessels, oil well drilling equipment, farm equipment, buildings, race cars, and more. As a vocational teacher, I have taught in high schools, schools for special education, schools for the deaf, and three colleges. I have also been a consultant to the welding industry.

Larry Jeffus is a recognized welding instructor with many years of experience teaching welding technology at the community college level. He has been actively involved in the American Welding Society, having served on the General Education Committee and as the chairman of the North Texas Section of the American Welding Society.

Index of Experiments and Practices

The following Experiments and Practices are listed in the order in which they appear in the chapter. It should be noted that not all chapters have Experiments and Practices.

Chapter 3

Experiment 3-1	Estimating Amperages	54
Experiment 3-2	Calculating the Amperage Setting	54
Practice 3-1	Estimating Amperages	55
Practice 3-2	Calculating Amperages	55
Practice 3-3	Reading Duty Cycle Chart	58
Practice 3-4	Determining Welding Lead Sizes	59
Practice 3-5	Repairing Electrode Holders	60

Chapter 4

Practice 4-1	Shielded Metal Arc Welding Safety	66
Experiment 4-1	Striking the Arc	66
Experiment 4-2	Striking the Arc Accurately	67
Experiment 4-3	Effects of Amperage Changes on a Weld Bead	68
Experiment 4-4	Excessive Heat	69
Experiment 4-5	Effect of Changing the Arc Length on a Weld	70
Experiment 4-6	Effect of Changing the Electrode Angle on a Weld	71
Practice 4-2	Straight Stringer Beads in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	76
Practice 4-3	Stringer Beads in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	77
Practice 4-4	Horizontal Stringer Beads Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	77
Practice 4-5	Welded Square Butt Joint in the Flat Position (1G) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	79
Practice 4-6	Vertical (3G) Up-Welded Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	80
Practice 4-7	Welded Horizontal (2G) Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	80
Practice 4-8	Edge Weld in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	82
Practice 4-9	Edge Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	82
Practice 4-10	Edge Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	82
Practice 4-11	Edge Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	84
Practice 4-12	Edge Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	85
Practice 4-13	Outside Corner Joint in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	86
Practice 4-14	Outside Corner Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	87
Practice 4-15	Outside Corner Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	87
Practice 4-16	Outside Corner Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	87
Practice 4-17	Outside Corner Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	89

Practice 4-18	Welded Lap Joint in the Flat Position (1F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	90
Practice 4-19	Welded Lap Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	92
Practice 4-20	Lap Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	92
Practice 4-21	Lap Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	92
Practice 4-22	Tee Joint in the Flat Position (1F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	94
Practice 4-23	Tee Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	94
Practice 4-24	Tee Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	94
Practice 4-25	Tee Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	96

Chapter 5

Practice 5-1	Beading, 1G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	110
Practice 5-2	Butt Joint, 1G Position, Using E6010 or E6011 Electrodes	111
Practice 5-3	Butt Joint, 1G Position, Using E6010 or E6011 Electrodes for the Root Pass with E7018 Electrodes for the Filler and Cover Passes	113
Practice 5-4	Stringer Bead, 2G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	114
Practice 5-5	Butt Joint, 2G Position, Using E6010 or E6011 Electrodes	114
Practice 5-6	Butt Joint, 2G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes	115
Practice 5-7	Stringer Bead, 5G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	116
Practice 5-8	Butt Joint, 5G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes	116
Practice 5-9	Butt Joint, 5G Position, Using E6010 or E6011 Electrodes	116
Practice 5-10	Stringer Bead, 6G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	117
Practice 5-11	Butt Joint, 6G Position, Using E6010 or E6011 Electrodes	117
Practice 5-12	Butt Joint, 6G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes	117

Chapter 6

Practice 6-1	Root Pass on Plate with a Backing Strip in All Positions	124
Practice 6-2	Root Pass on Plate with an Open Root in All Positions	124
Practice 6-3	Open Root Weld on Plate Using the Step Technique in All Positions	126
Experiment 6-1	Hot Pass to Repair a Poor Weld Bead	129
Practice 6-4	Multiple Pass Filler Weld on a V-joint in All Positions	130
Practice 6-5	Multiple Pass Filler Weld on a V-joint in All Positions Using E7018 Electrodes	130
Practice 6-6	Cover Bead in All Positions	131
Practice 6-7	Welding Procedure Specification (WPS)	137
Practice 6-8	Welding Procedure Specification (WPS)	138
Practice 6-9	Welding Procedure Specification (WPS)	141
Practice 6-10	Single V-groove Open Root Butt Joint with an Increasing Root Opening	144
Practice 6-11	Single V-groove Open Root Butt Joint with a Decreasing Root Opening	144

Chapter 7

Practice 7-1	Setting Up a Cutting Torch	158
Practice 7-2	Cleaning a Cutting Tip	158
Practice 7-3	Lighting the Torch	159
Practice 7-4	Setting the Gas Pressures	164
Experiment 7-1	Observing Heat Produced during a Cut	166
Experiment 7-2	Effect of Flame, Speed, and Pressure on a Machine Cut	167
Experiment 7-3	Effect of Flame, Speed, and Pressure on a Hand Cut	168
Practice 7-5	Flat, Straight Cut in Thin Plate	169
Practice 7-6	Flat, Straight Cut in Thick Plate	170

Practice 7-7	Flat, Straight Cut in Sheet Metal	170
Practice 7-8	Flame Cutting Holes	170
Experiment 7-4	Minimizing Distortion	171
Practice 7-9	Beveling a Plate	171
Practice 7-10	Vertical Straight Cut	171
Practice 7-11	Overhead Straight Cut	172
Practice 7-12	Cutting Out Internal and External Shapes	173
Practice 7-13	Square Cut on Pipe, 1G (Horizontal Rolled) Position	174
Practice 7-14	Square Cut on Pipe, 1G (Horizontal Rolled) Position	174
Practice 7-15	Square Cut on Pipe, 5G (Horizontal Fixed) Position	175
Practice 7-16	Square Cut on Pipe, 2G (Vertical) Position	175

Chapter 8

Practice 8-1	Flat, Straight Cuts in Thin Plate	193
Practice 8-2	Flat, Straight Cuts in Thick Plate	193
Practice 8-3	Flat Cutting Holes	194
Practice 8-4	Beveling of a Plate	195
Practice 8-5	U-grooving of a Plate	195

Chapter 9

Practice 9-1	Air Carbon Arc Straight Cut in the Flat Position	208
Practice 9-2	Air Carbon Arc Edge Cut in the Flat Position	209
Practice 9-3	Air Carbon Arc Back Gouging in the Flat Position	210
Practice 9-4	Air Carbon Arc Weld Removal in the Flat Position	210

Chapter 11

Practice 11-1	GMAW Equipment Setup	243
Practice 11-2	Threading GMAW Wire	245
Experiment 11-1	Setting Gas Flow Rate	248
Experiment 11-2	Setting the Current	249
Experiment 11-3	Electrode Extension	251
Experiment 11-4	Welding Gun Angle	252
Experiment 11-5	Effect of Shielding Gas Changes	253
Practice 11-3	Stringer Beads Using the Short-circuiting Metal Transfer Method in the Flat Position	256
Practice 11-4	Flat Position Butt Joint, Lap Joint, and Tee Joint	258
Practice 11-5	Flat Position Butt Joint, Lap Joint, and Tee Joint, All with 100% Penetration	258
Practice 11-6	Flat Position Butt Joint, Lap Joint, and Tee Joint, All Welds to Be Tested	260
Practice 11-7	Stringer Bead at a 45° Vertical Up Angle	260
Practice 11-8	Stringer Bead in the Vertical Up Position	262
Practice 11-9	Butt Joint, Lap Joint, and Tee Joint in the Vertical Up Position at a 45° Angle	262
Practice 11-10	Butt Joint, Lap Joint, and Tee Joint in the Vertical Up Position with 100% Penetration	262
Practice 11-11	Butt Joint, Lap Joint, and Tee Joint in the Vertical Up Position, All Welds to Be Tested	262
Practice 11-12	Stringer Bead at a 45° Vertical Down Angle	263
Practice 11-13	Stringer Bead in the Vertical Down Position	263
Practice 11-14	Butt Joint, Lap Joint, and Tee Joint in the Vertical Down Position	263
Practice 11-15	Butt Joint and Tee Joint in the Vertical Down Position with 100% Penetration	263
Practice 11-16	Butt Joint and Tee Joint in the Vertical Down Position, Welds to Be Tested	264
Practice 11-17	Horizontal Stringer Bead at a 45° Angle	264
Practice 11-18	Stringer Bead in the Horizontal Position	264
Practice 11-19	Butt Joint, Lap Joint, and Tee Joint in the Horizontal Position	265
Practice 11-20	Butt Joint and Tee Joint in the Horizontal Position with 100% Penetration	265
Practice 11-21	Butt Joint and Tee Joint in the Horizontal Position, Welds to Be Tested	265
Practice 11-22	Stringer Bead Overhead Position	265
Practice 11-23	Butt Joint, Lap Joint, and Tee Joint in the Overhead Position	266
Practice 11-24	Butt Joint and Tee Joint in the Overhead Position with 100% Penetration	267
Practice 11-25	Butt Joint and Tee Joint in the Overhead Position, Welds to Be Tested	267
Practice 11-26	Stringer Bead	267

Practice 11-27	Butt Joint	268
Practice 11-28	Butt Joint with 100% Penetration	268
Practice 11-29	Butt Joint to Be Tested	270
Practice 11-30	Tee Joint and Lap Joint in the 1F Position	270
Practice 11-31	Tee Joint and Lap Joint in the 2F Position	270
Practice 11-32	Stringer Bead, 1G Position	270
Practice 11-33	Butt Joint, Lap Joint, and Tee Joint Using the Axial Spray Method	270
Practice 11-34	Butt Joint and Tee Joint	271

Chapter 13

Practice 13-1	FCAW Equipment Setup	296
Practice 13-2	Threading FCAW Wire	298
Practice 13-3	Stringer Beads Flat Position	299
Practice 13-4	Butt Joint 1G	301
Practice 13-5	Butt Joint 1G 100% to Be Tested	301
Practice 13-6	Butt Joint 1G	304
Practice 13-7	Butt Joint 1G 100% to Be Tested	305
Practice 13-8	Butt Joint 1G	306
Practice 13-9	Butt Joint 1G 100% to Be Tested	306
Practice 13-10	Lap Joint and Tee Joint 1F	308
Practice 13-11	Lap Joint and Tee Joint 1F 100% to Be Tested	311
Practice 13-12	Tee Joint 1F	311
Practice 13-13	Tee Joint 1F 100% to Be Tested	311
Practice 13-14	Butt Joint at a 45° Vertical Up Angle	313
Practice 13-15	Butt Joint 3G	314
Practice 13-16	Butt Joint 3G 100% to Be Tested	314
Practice 13-17	Butt Joint 3G	315
Practice 13-18	Butt Joint 3G 100% to Be Tested	315
Practice 13-19	Butt Joint at a 45° Vertical Up Angle	315
Practice 13-20	Butt Joint 3G	316
Practice 13-21	Butt Joint 3G 100% to Be Tested	316
Practice 13-22	Fillet Weld Joint at a 45° Vertical Up Angle	316
Practice 13-23	Lap Joint and Tee Joint 3F	317
Practice 13-24	Lap Joint and Tee Joint 3F 100% to Be Tested	317
Practice 13-25	Tee Joint 3F	317
Practice 13-26	Tee Joint 3F 100% to Be Tested	317
Practice 13-27	Lap Joint and Tee Joint 2F	318
Practice 13-28	Lap Joint and Tee Joint 2F 100% to Be Tested	318
Practice 13-29	Tee Joint 2F	320
Practice 13-30	Tee Joint 2F 100% to Be Tested	320
Practice 13-31	Stringer Bead at a 45° Horizontal Angle	320
Practice 13-32	Butt Joint 2G	320
Practice 13-33	Butt Joint 2G 100% to Be Tested	320
Practice 13-34	Butt Joint 2G	322
Practice 13-35	Butt Joint 2G 100% to Be Tested	322
Practice 13-36	Butt Joint 2G	322
Practice 13-37	Butt Joint 2G 100% to Be Tested	323
Practice 13-38	Butt Joint 4G	323
Practice 13-39	Butt Joint 4G 100% to Be Tested	323
Practice 13-40	Butt Joint 4G	324
Practice 13-41	Butt Joint 4G 100% to Be Tested	324
Practice 13-42	Butt Joint 4G	324
Practice 13-43	Butt Joint 4G 100% to Be Tested	325
Practice 13-44	Lap Joint and Tee Joint 4F	325
Practice 13-45	Lap Joint and Tee Joint 4F 100% to Be Tested	325
Practice 13-46	Tee Joint 4F	326
Practice 13-47	Tee Joint 4F 100% to Be Tested	326
Practice 13-48	Butt Joint 1G	327
Practice 13-49	Butt Joint 1G 100% to Be Tested	328
Practice 13-50	Lap Joint and Tee Joint 1F	328
Practice 13-51	Lap Joint and Tee Joint 1F 100% to Be Tested	328

Practice 13-52	Butt Joint 3G	330
Practice 13-53	Butt Joint 3G 100% to Be Tested	330
Practice 13-54	Lap Joint and Tee Joint 3F	330
Practice 13-55	Lap Joint and Tee Joint 3F 100% to Be Tested	330
Practice 13-56	Lap Joint and Tee Joint 2F	330
Practice 13-57	Lap Joint and Tee Joint 2F 100% to Be Tested	331
Practice 13-58	Butt Joint 2G	331
Practice 13-59	Butt Joint 2G 100% to Be Tested	331
Practice 13-60	Butt Joint 4G	331
Practice 13-61	Butt Joint 4G 100% to Be Tested	331
Practice 13-62	Lap Joint and Tee Joint 4F	331
Practice 13-63	Lap Joint and Tee Joint 4F 100% to Be Tested	332

Chapter 14

Experiment 14-1	SA Welding	340
------------------------	----------------------	-----

Chapter 15

Experiment 15-1	Grinding the Tungsten to the Desired Shape	351
Experiment 15-2	Removing a Contaminated Tungsten End by Breaking	352
Experiment 15-3	Melting the Tungsten End Shape	353
Experiment 15-4	Setting Up a GTA Welder	363
Experiment 15-5	Striking an Arc	365

Chapter 16

Experiment 16-1	Setting the Welding Current	374
Experiment 16-2	Setting Gas Flow	376
Practice 16-1	Stringer Beads, Flat Position, on Mild Steel	379
Practice 16-2	Stringer Beads, Flat Position, on Stainless Steel	380
Practice 16-3	Stringer Beads, Flat Position, on Aluminum	381
Practice 16-4	Flat Position, Using Mild Steel, Stainless Steel, Aluminum	381
Practice 16-5	Outside Corner Joint, 1G Position, Using Mild Steel, Stainless Steel, Aluminum	383
Practice 16-6	Butt Joint, 1G Position, Using Mild Steel, Stainless Steel, Aluminum	384
Practice 16-7	Butt Joint, 1G Position, with 100% Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	384
Practice 16-8	Butt Joint, 1G Position, with Minimum Distortion, Using Mild Steel, Stainless Steel, Aluminum	385
Practice 16-9	Lap Joint, 1F Position, Using Mild Steel, Stainless Steel, Aluminum	386
Practice 16-10	Lap Joint, 1F Position, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	386
Practice 16-11	Tee Joint, 1F Position, Using Mild Steel, Stainless Steel, Aluminum	388
Practice 16-12	Tee Joint, 1F Position, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	388
Practice 16-13	Stringer Bead at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum	390
Practice 16-14	Stringer Bead, 3G Position, Using Mild Steel, Stainless Steel, Aluminum	390
Practice 16-15	Butt Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum	391
Practice 16-16	Butt Joint, 3G Position, Using Mild Steel, Stainless Steel, Aluminum	391
Practice 16-17	Butt Joint, 3G Position, with 100% Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	393
Practice 16-18	Lap Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum	393
Practice 16-19	Lap Joint, 3F Position, Using Mild Steel, Stainless Steel, Aluminum	393
Practice 16-20	Lap Joint, 3F Position, with 100% Root Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	394
Practice 16-21	Tee Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum	395
Practice 16-22	Tee Joint, 3F Position, Using Mild Steel, Stainless Steel, Aluminum	395
Practice 16-23	Tee Joint, 3F Position, with 100% Root Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	395
Practice 16-24	Stringer Bead at a 45° Reclining Angle, Using Mild Steel, Stainless Steel, Aluminum	395
Practice 16-25	Stringer Bead, 2G Position, Using Mild Steel, Stainless Steel, Aluminum	395
Practice 16-26	Butt Joint, 2G Position, Using Mild Steel, Stainless Steel, Aluminum	396
Practice 16-27	Butt Joint, 2G Position, with 100% Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	396

Practice 16-28	Lap Joint, 2F Position, Using Mild Steel, Stainless Steel, Aluminum	396
Practice 16-29	Lap Joint, 2F Position, with 100% Root Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	397
Practice 16-30	Tee Joint, 2F Position, Using Mild Steel, Stainless Steel, Aluminum	397
Practice 16-31	Tee Joint, 2F Position, with 100% Root Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum	397
Practice 16-32	Stringer Bead, 4G Position, Using Mild Steel, Stainless Steel, Aluminum	398
Practice 16-33	Butt Joint, 4G Position, Using Mild Steel, Stainless Steel, Aluminum	398
Practice 16-34	Lap Joint, 4F Position, Using Mild Steel, Stainless Steel, Aluminum	398
Practice 16-35	Tee Joint, 4F Position, Using Mild Steel, Stainless Steel, Aluminum	398

Chapter 17

Practice 17-1	Tack Welding Pipe	408
Practice 17-2	Root Pass, Horizontal Rolled Position (1G)	410
Experiment 17-1	Repairing a Root Pass Using a Hot Pass	412
Practice 17-3	Stringer Bead, Horizontal Rolled Position (1G)	413
Practice 17-4	Weave and Lace Beads, Horizontal Rolled Position (1G)	414
Practice 17-5	Filler Pass (1G Position)	415
Practice 17-6	Cover Pass (1G Position)	416
Practice 17-7	Single V-groove Pipe Weld, 1G Position, to Be Tested	416
Practice 17-8	Stringer Bead, Horizontal Fixed Position (5G)	416
Practice 17-9	Single-V Butt Joint (5G Position) A. Root Penetration May Vary B. 100% Root Penetration to Be Tested	418
Practice 17-10	Stringer Bead, Vertical Fixed Position (2G)	419
Practice 17-11	Single-V Butt Joint (2G Position) A. Root Penetration May Vary B. 100% Root Penetration to Be Tested	420
Practice 17-12	Stringer Bead on a Fixed Pipe at a 45° Inclined Angle (6G Position)	421
Practice 17-13	Single-V Butt Joint (6G Position) A. Root Penetration May Vary B. 100% Root Penetration to Be Tested	421

Chapter 18

Practice 18-1	Layout Square, Rectangular, and Triangular Parts	458
Practice 18-2	Laying Out Circles, Arcs, and Curves	458
Practice 18-3	Nesting Layout	458
Practice 18-4	Bill of Materials	458
Practice 18-5	Allowing Space for the Kerf	459

Chapter 19

Practice 19-1	Writing a Welding Procedure Specification (WPS)	480
Practice 19-2	Procedure Qualification Record (PQR)	487
Practice 19-3	Finding Weld Groove Volume	491
Practice 19-4	Calculate the Weight of Material	492

Chapter 21

Practice 21-1	Welder Qualification Test Plate for Limited Thickness Horizontal 2G Position with E7018 Electrodes	548
Practice 21-2	Welder Qualification Test Plate for Limited Thickness Vertical 3G Position with E7018 Electrodes	552
Practice 21-3	Gas Metal Arc Welding—Short-circuit Metal Transfer (GMAW-S)	555
Practice 21-4	Flux Cored Arc Welding—Gas Shielded (FCAW-G)	558
Practice 21-5	Flux Cored Arc Welding Self-shielded (FCAW)	561
Practice 21-6	Gas Metal Arc Welding Spray Transfer (GMAW)	564
Practice 21-7	Gas Tungsten Arc Welding on Plain Carbon Steel (GTAW)	567
Practice 21-8	Gas Tungsten Arc Welding on Stainless Steel (GTAW)	571
Practice 21-9	Gas Tungsten Arc Welding on Aluminum (GTAW)	575
Practice 21-10	Welder and Welder Operator Qualification Test Record (WPS)	579

Chapter 23

Experiment 23-1	Latent and Sensible Heat	607
Experiment 23-2	Temper Colors	608
Experiment 23-3	Crystal Formation.	618
Experiment 23-4	Effect of Quenching and Tempering on Metal Properties	619

Chapter 24

Experiment 24-1	Identifying Metal Using a Spark Test	643
------------------------	--	-----

Chapter 28

Experiment 28-1	Line Resistance	721
Practice 28-1	Setting Up an Oxyfuel Torch Set	734
Practice 28-2	Turning On and Testing a Torch	735
Practice 28-3	Lighting and Adjusting an Oxyacetylene Flame.	738
Practice 28-4	Shutting Off and Disassembling Oxyfuel Welding Equipment	739

Chapter 29

Experiment 29-1	Burn Rate	747
Experiment 29-2	Oxyfuel Flames.	754

Chapter 30

Experiment 30-1	Flame Effect on Metal.	763
Practice 30-1	Pushing a Molten Weld Pool	764
Experiment 30-2	Effect of Torch Angle and Torch Height Changes	765
Practice 30-2	Beading.	765
Experiment 30-3	Effect of Rod Size on the Molten Weld Pool	767
Practice 30-3	Stringer Bead, Flat Position	768
Practice 30-4	Outside Corner Joint, Flat Position	768
Practice 30-5	Butt Joint, Flat Position	770
Practice 30-6	Butt Joint with 100% Penetration.	770
Practice 30-7	Butt Joint with Minimum Distortion	771
Practice 30-8	Lap Joint, Flat Position.	772
Practice 30-9	Tee Joint, Flat Position	774
Practice 30-10	Stringer Bead at a 45° Angle	776
Practice 30-11	Stringer Bead, Vertical Position	777
Practice 30-12	Butt Joint at a 45° Angle	777
Practice 30-13	Butt Joint, Vertical Position	777
Practice 30-14	Butt Joint, Vertical Position, with 100% Penetration	778
Practice 30-15	Lap Joint at a 45° Angle	778
Practice 30-16	Lap Joint, Vertical Position.	779
Practice 30-17	Tee Joint at a 45° Angle	779
Practice 30-18	Tee Joint, Vertical Position.	779
Practice 30-19	Horizontal Stringer Bead at a 45° Sheet Angle	780
Practice 30-20	Stringer Bead, Horizontal Position	780
Practice 30-21	Butt Joint, Horizontal Position.	780
Practice 30-22	Lap Joint, Horizontal Position	781
Practice 30-23	Tee Joint, Horizontal Position	781
Practice 30-24	Stringer Bead, Overhead Position.	781
Practice 30-25	Butt Joint, Overhead Position.	782
Practice 30-26	Lap Joint, Overhead Position	782
Practice 30-27	Tee Joint, Overhead Position	782
Experiment 30-4	Effect of Changing Angle on Molten Weld Pool	783
Experiment 30-5	Stringer Bead, 1G Position	783
Experiment 30-6	Stops and Starts.	784
Practice 30-28	Stringer Bead, 1G Position	784
Practice 30-29	Butt Joint, 1G Position	784
Experiment 30-7	5G Position	786
Practice 30-30	Stringer Bead, 5G Position	786

Practice 30-31	Butt Joint, 5G Position	786
Practice 30-32	Stringer Bead, 2G Position	787
Practice 30-33	Butt Joint, 2G Position	787
Practice 30-34	Stringer Bead, 6G Position	787
Practice 30-35	Butt Joint, 6G Position	788

Chapter 31

Experiment 31-1	Paste Range	802
Experiment 31-2	Fluxing Action	806
Experiment 31-3	Uniform Heating	807
Experiment 31-4	Tinning or Phase Temperature	807
Practice 31-1	Brazed Stringer Bead	808
Practice 31-2	Brazed Butt Joint	808
Practice 31-3	Brazed Butt Joint with 100% Penetration	809
Practice 31-4	Brazed Tee Joint	809
Practice 31-5	Brazed Lap Joint	809
Practice 31-6	Brazed Lap Joint with 100% Penetration	811
Practice 31-7	Brazed Tee Joint, Thin to Thick Metal	811
Practice 31-8	Brazed Lap Joint, Thin to Thick Metal	812
Practice 31-9	Braze Welded Butt Joint, Thick Metal	813
Practice 31-10	Braze Welded Tee Joint, Thick Metal	813
Practice 31-11	Braze Welding to Fill a Hole	814
Practice 31-12	Flat Surface Buildup	814
Practice 31-13	Round Surface Buildup	815
Practice 31-14	Silver Brazing Copper Pipe, 2G Vertical Down Position	816
Practice 31-15	Silver Brazing Copper Pipe, 5G Horizontal Fixed Position	818
Practice 31-16	Silver Brazing Copper Pipe, 2G Vertical Up Position	818
Practice 31-17	Soldered Tee Joint	819
Practice 31-18	Soldered Lap Joint	819
Practice 31-19	Soldering Copper Pipe, 2G Vertical Down Position	819
Practice 31-20	Soldering Copper Pipe, 1G Position	820
Practice 31-21	Soldering Copper Pipe, 4G Vertical Up Position	820
Practice 31-22	Soldering Aluminum to Copper	821