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
**Contents**

**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  
Backin g ..................................................................... 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
Chapter 25  Filler Metal Selection

Introduction .................................................. 649
Manufacturers’ Electrode Information .............. 655
Understanding the Electrode Data ................. 655
Data Resulting from Mechanical Tests .......... 655
Data Resulting from Chemical Analysis ........ 655
Carbon Equivalent (CE) ................................. 656
 SMAW Operating Information ......................... 656
Core Wire ....................................................... 657
Functions of the Flux Covering ...................... 657
Filler Metal Selection ................................... 658
AWS Filler Metal Classifications ................. 659
Carbon Steel .................................................. 659
Aluminum and Aluminum Alloys ................. 667
Summary ....................................................... 670
Filler Metal Made Easy ................................. 671
Review .......................................................... 672

Chapter 26  Welding Automation and Robotics

Introduction .................................................. 674
Manual Joining Process ................................. 675
Semiautomatic Joining Processes .................. 676
Machine Joining Processes ......................... 677
Automatic Joining Processes ......................... 677
Automated Joining ....................................... 678
Industrial Robots ......................................... 679
Future Automation ........................................ 685
Summary ....................................................... 690
Improving Productivity with Robotic Welding ... 690
Review .......................................................... 692

Chapter 27  Other Welding Processes

Introduction .................................................. 693
Resistance Welding (RW) .............................. 694
Electron Beam Welding (EBW) ...................... 699
Ultrasonic Welding (USW) .............................. 702
Inertial Welding Process ............................... 703
Laser Welding (LBW) ...................................... 706
Plasma-arc Welding Process (PAW) ............... 707
Stud Welding (SW) ......................................... 708
Hardfacing ..................................................... 708
Thermal Spraying (THSP) .............................. 711
Cold Welding (CW) ......................................... 713
Summary ....................................................... 714
Extending the Life of Resistance Welding Electrodes ................................. 715
Review .......................................................... 717

SECTION 7  OXYFUEL

Chapter 28  Oxyfuel Welding and Cutting

Equipment, Setup, and Operation

Introduction .................................................. 720
Pressure Regulators ....................................... 721
Welding and Cutting Torches Design and Service ................................. 726
Welding and Heating Tips .............................. 729
Reverse Flow and Flashback Valves ............... 730
Hoses and Fittings ......................................... 732
Backfires and Flashbacks .............................. 733
Types of Flames ............................................. 734
Leak Detection .............................................. 734
Manifold Systems ......................................... 739
Summary ....................................................... 741
Steel Center Consolidates Cutting Operations to Cut Costs .................. 741
Review .......................................................... 743

Chapter 29  Oxyfuel Gases and Filler Metals

Introduction .................................................. 744
Uses of the Oxyfuel Flame ............................. 745
Characteristics of the Fuel-gas Flame ............. 745
Fuel Gases ..................................................... 745
Flame Rate of Burning ................................... 746
Acetylene (C2H2) .......................................... 748
Liquefied Fuel Gases ..................................... 750
Propane and Natural Gas .............................. 753
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

Glossary.....................................................................875

Index ......................................................................881
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 ArcWorks™, 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 discussed 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:
1. Explain the operating principles for the different special welding gases.
2. Use the operational features of each special welding process described in this chapter.

KEY TERMS
dissolved oxygen
indicator lamp
methane
natural gas
nitrogen
gas welding
oxygen
gas welding equipment

INTRODUCTION
Oxyfuel welding and cutting equipment and allied processes are listed by the American Welding Society in the commonly used processes that require the welder to have a skillful ability. This chapter contains some of the additional processes that utilize special equipment and are designed for those processes. The book is intended for those who are interested in learning about the operation of oxyfuel equipment and who are interested in welding and cutting processes. The book contains the information and training, such as equipment, welding, and cutting processes.

Table 29-6

<table>
<thead>
<tr>
<th>Application</th>
<th>Acetylene</th>
<th>CO₂</th>
<th>O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beveling</td>
<td>100 100</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Cutting dirty or scaled surfaces</td>
<td>100 95</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting low alloy specialty steels</td>
<td>100 90</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting over 5 in. thick</td>
<td>80 100</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Gouging</td>
<td>95 100</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Hardfacing</td>
<td>100 0 0</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting rounds</td>
<td>95 100</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Cutting rounds</td>
<td>95 100</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Cutting over 5 in. thick</td>
<td>80 100</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Cutting dirty or scaled surfaces</td>
<td>100 95</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting low alloy specialty steels</td>
<td>100 90</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting over 5 in. thick</td>
<td>80 100</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Cutting dirty or scaled surfaces</td>
<td>100 95</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting low alloy specialty steels</td>
<td>100 90</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Cutting over 5 in. thick</td>
<td>80 100</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Water quenching</td>
<td>75 100</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>
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.

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.
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
- 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 Knetz; 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 Burrus, and Bernice Nolan for all the hours spent helping in the preparation of this edition
- Kristi Webb; Sam Burrus; Ben Burrus; 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

<table>
<thead>
<tr>
<th>Experiment 3-1</th>
<th>Estimating Amperages</th>
<th>54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 3-2</td>
<td>Calculating the Amperage Setting</td>
<td>54</td>
</tr>
<tr>
<td>Practice 3-1</td>
<td>Estimating Amperages</td>
<td>55</td>
</tr>
<tr>
<td>Practice 3-2</td>
<td>Calculating Amperages</td>
<td>55</td>
</tr>
<tr>
<td>Practice 3-3</td>
<td>Reading Duty Cycle Chart</td>
<td>58</td>
</tr>
<tr>
<td>Practice 3-4</td>
<td>Determining Welding Lead Sizes</td>
<td>59</td>
</tr>
<tr>
<td>Practice 3-5</td>
<td>Repairing Electrode Holders</td>
<td>60</td>
</tr>
</tbody>
</table>

#### Chapter 4

<table>
<thead>
<tr>
<th>Practice 4-1</th>
<th>Shielded Metal Arc Welding Safety</th>
<th>66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 4-1</td>
<td>Striking the Arc</td>
<td>66</td>
</tr>
<tr>
<td>Experiment 4-2</td>
<td>Striking the Arc Accurately</td>
<td>67</td>
</tr>
<tr>
<td>Experiment 4-3</td>
<td>Effects of Amperage Changes on a Weld Bead</td>
<td>68</td>
</tr>
<tr>
<td>Experiment 4-4</td>
<td>Excessive Heat</td>
<td>69</td>
</tr>
<tr>
<td>Experiment 4-5</td>
<td>Effect of Changing the Arc Length on a Weld</td>
<td>70</td>
</tr>
<tr>
<td>Experiment 4-6</td>
<td>Effect of Changing the Electrode Angle on a Weld</td>
<td>71</td>
</tr>
<tr>
<td>Practice 4-2</td>
<td>Straight Stringer Beads in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>76</td>
</tr>
<tr>
<td>Practice 4-3</td>
<td>Stringer Beads in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>77</td>
</tr>
<tr>
<td>Practice 4-4</td>
<td>Horizontal Stringer Beads Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>77</td>
</tr>
<tr>
<td>Practice 4-5</td>
<td>Welded Square Butt Joint in the Flat Position (1G) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>79</td>
</tr>
<tr>
<td>Practice 4-6</td>
<td>Vertical (3G) Up-Welded Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>80</td>
</tr>
<tr>
<td>Practice 4-7</td>
<td>Welded Horizontal (2G) Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>80</td>
</tr>
<tr>
<td>Practice 4-8</td>
<td>Edge Weld in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>82</td>
</tr>
<tr>
<td>Practice 4-9</td>
<td>Edge Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>82</td>
</tr>
<tr>
<td>Practice 4-10</td>
<td>Edge Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>82</td>
</tr>
<tr>
<td>Practice 4-11</td>
<td>Edge Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>84</td>
</tr>
<tr>
<td>Practice 4-12</td>
<td>Edge Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>85</td>
</tr>
<tr>
<td>Practice 4-13</td>
<td>Outside Corner Joint in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>86</td>
</tr>
<tr>
<td>Practice 4-14</td>
<td>Outside Corner Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>87</td>
</tr>
<tr>
<td>Practice 4-15</td>
<td>Outside Corner Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>87</td>
</tr>
<tr>
<td>Practice 4-16</td>
<td>Outside Corner Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>87</td>
</tr>
<tr>
<td>Practice 4-17</td>
<td>Outside Corner Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes</td>
<td>89</td>
</tr>
</tbody>
</table>
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 ................................. 91
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
Index of Experiments and Practices

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
Index of Experiments and Practices

Chapter 14

Experiment 14-1
SA Welding

Chapter 15

Experiment 15-1
Grinding the Tungsten to the Desired Shape

Experiment 15-2
Removing a Contaminated Tungsten End by Breaking

Experiment 15-3
Melting the Tungsten End Shape

Experiment 15-4
Setting Up a GTA Welder

Experiment 15-5
Striking an Arc

Chapter 16

Experiment 16-1
Setting the Welding Current

Experiment 16-2
Setting Gas Flow

Practice 16-1
Stringer Beads, Flat Position, on Mild Steel

Practice 16-2
Stringer Beads, Flat Position, on Stainless Steel

Practice 16-3
Stringer Beads, Flat Position, on Aluminum

Practice 16-4
Flat Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-5
Outside Corner Joint, 1F Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-6
Butt Joint, 1G Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-7
Butt Joint, 1G Position, with 100% Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-8
Butt Joint, 1G Position, with Minimum Distortion, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-9
Lap Joint, 1F Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-10
Lap Joint, 1F Position, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-11
Tee Joint, 1F Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-12
Tee Joint, 1F Position, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-13
Stringer Bead at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-14
Stringer Bead, 3G Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-15
Butt Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-16
Butt Joint, 3G Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-17
Butt Joint, 3G Position, with 100% Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-18
Lap Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-19
Lap Joint, 3F Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-20
Lap Joint, 3F Position, with 100% Root Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-21
Tee Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-22
Tee Joint, 3F Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-23
Tee Joint, 3F Position, with 100% Root Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-24
Stringer Bead at a 45° Reclining Angle, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-25
Stringer Bead, 2G Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-26
Butt Joint, 2G Position, Using Mild Steel, Stainless Steel, Aluminum

Practice 16-27
Butt Joint, 2G Position, with 100% Penetration, to Be Tested, Using Mild Steel, Stainless Steel, Aluminum
Index of Experiments and Practices

Chapter 23
- Experiment 23-1: Latent and Sensible Heat
- Experiment 23-2: Temper Colors
- Experiment 23-3: Crystal Formation
- Experiment 23-4: Effect of Quenching and Tempering on Metal Properties

Chapter 24
- Experiment 24-1: Identifying Metal Using a Spark Test

Chapter 28
- Experiment 28-1: Line Resistance
- Practice 28-1: Setting Up an Oxyfuel Torch Set
- Practice 28-2: Turning On and Testing a Torch
- Practice 28-3: Lighting and Adjusting an Oxyacetylene Flame
- Practice 28-4: Shutting Off and Disassembling Oxyfuel Welding Equipment

Chapter 29
- Experiment 29-1: Burn Rate
- Experiment 29-2: Oxyfuel Flames

Chapter 30
- Experiment 30-1: Flame Effect on Metal
- Practice 30-1: Pushing a Molten Weld Pool
- Experiment 30-2: Effect of Torch Angle and Torch Height Changes
- Practice 30-2: Beading
- Experiment 30-3: Effect of Rod Size on the Molten Weld Pool
- Practice 30-3: Stringer Bead, Flat Position
- Practice 30-4: Outside Corner Joint, Flat Position
- Practice 30-5: Butt Joint, Flat Position
- Practice 30-6: Butt Joint with 100% Penetration
- Practice 30-7: Butt Joint with Minimum Distortion
- Practice 30-8: Lap Joint, Flat Position
- Practice 30-9: Tee Joint, Flat Position
- Practice 30-10: Stringer Bead at a 45° Angle
- Practice 30-11: Stringer Bead, Vertical Position
- Practice 30-12: Butt Joint at a 45° Angle
- Practice 30-13: Butt Joint, Vertical Position
- Practice 30-14: Butt Joint, Vertical Position, with 100% Penetration
- Practice 30-15: Lap Joint at a 45° Angle
- Practice 30-16: Lap Joint, Vertical Position
- Practice 30-17: Tee Joint at a 45° Angle
- Practice 30-18: Tee Joint, Vertical Position
- Practice 30-19: Horizontal Stringer Bead at a 45° Sheet Angle
- Practice 30-20: Stringer Bead, Horizontal Position
- Practice 30-21: Butt Joint, Horizontal Position
- Practice 30-22: Lap Joint, Horizontal Position
- Practice 30-23: Tee Joint, Horizontal Position
- Practice 30-24: Stringer Bead, Overhead Position
- Practice 30-25: Butt Joint, Overhead Position
- Practice 30-26: Lap Joint, Overhead Position
- Practice 30-27: Tee Joint, Overhead Position
- Experiment 30-4: Effect of Changing Angle on Molten Weld Pool
- Experiment 30-5: Stringer Bead, 1G Position
- Experiment 30-6: Stops and Starts
- Practice 30-28: Stringer Bead, 1G Position
- Practice 30-29: Butt Joint, 1G Position
- Experiment 30-7: 5G Position
- Practice 30-30: Stringer Bead, 5G Position
| 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 |

| 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 |