Air Conditioning and Refrigeration
Air Conditioning and Refrigeration

REX MILLER
Professor Emeritus
State University College at Buffalo
Buffalo, New York

MARK R. MILLER
Professor, Industrial Technology
The University of Texas at Tyler
Tyler, Texas
Contents

Preface xv
Acknowledgments xvii

1 Air-Conditioning and Refrigeration Tools and Instruments

Performance Objectives 2
Tools and Equipment 2
Pliers and Clippers 2
Fuse Puller 2
Screwdrivers 2
Wrenches 3
Soldering Equipment 3
Drilling Equipment 4
Knives and Other Insulation-Stripping Tools 5
Meters and Test Prods 6
Tool Kits 7

Gages and Instruments 9
Pressure Gages 9
Gage Selection 10
Line Pressure 11
Effects of Temperature on Gage Performance 12
Care of Gages 12
Gage Recalibration 12

Thermometers 13
Pocket Thermometer 13
Bimetallic Thermometers 15
Thermocouple Thermometers 16
Resistance Thermometers 16
Superheat Thermometer 17

Superheat Measurement Instruments 17

Halide Leak Detectors 21
Setting Up 21
Lighting 22
Leak Testing the Setup 22
Adjusting the Flame 22
Detecting Leaks 22
Maintenance 22

Electrical Instruments 23
Ammeter 23

Voltmeter 25
Ohmmeter 26
Multimeter 26
Wattmeter 27

Other instruments 28
Air-Filter Efficiency Gages 28
Air-Measurement Instruments 28
Humidity-Measurement Instruments 29
Vibration and Sound Meters 29

Service Tools 30
Special Tools 31

Vacuum Pumps 32
Vacuum Pump Maintenance 34
Vacuum Pump Oil Problems 34
Operating Instructions 34
Evacuating a System 35

Charging Cylinder 35
Charging Oil 36
Changing Oil 37
Mobile Charging Stations 37

Tubing 37
Soft Copper Tubing 37
Hard-Drawn Copper Tubing 38
Cutting Copper Tubing 39
Flaring Copper Tubing 40
Constricting Tubing 41
Swaging Copper Tubing 41
Forming Refrigerant Tubing 42
Fitting Copper Tubing by Compression 43

Soldering 43
Soft Soldering 44
Silver Soldering or Brazing 46

Testing for leaks 47
Cleaning and Degreasing Solvents 47
Review Questions 47

2 Development of Refrigeration

Performance Objectives 50
Historical Development 50
Structure of Matter  50
Elements 51
Atom 51
Properties of Matter 51
Pressure 52
Pressure Indicating Devices 52
Pressure of Liquids and Gases 53
Atmospheric Pressure 53
Gage Pressure 53
Absolute Pressure 53
Compression Ratio 54
Temperature and Heat 54
Specific Heat 55
Heat Content 55
Sensible Heat 55
Latent Heat 55
Other Sources of Heat 56
Refrigeration Systems 56
Refrigeration from Vaporization
(Open System) 56
Basic Refrigeration Cycle 56
Capacity 57
Refrigerants 57
Refrigerant Replacements and the Atmosphere 58
Review Questions 59

3 Voltage, Current, and Resistance
Performance Objectives 62
Ohm’s Law 62
Series Circuits 62
Parallel Circuits 64
Current in a Parallel Circuit 64
Resistance in a Parallel Circuit 65
AC and DC Power 65
Phase 66
Power in DC Circuits 66
Power Rating of Equipment 67
Capacitors 67
How a Capacitor Works 68
Capacity of a Capacitor 69
Dielectric Failure 69
Basic Units of Capacitance 69
Working with Capacitive Values 69
Capacitor Types 70
Capacitor Tolerances 73
The AC Circuit and the Capacitor 73
Uses of Capacitors 75
Inductance 75
Four Methods of Changing Inductance 75
Self-Inductance 75
Mutual Inductance 76
Inductive Reactance 77
Uses of Inductive Reactances 77
Transformers 77
Transformer Construction 77

4 Solenoids and Valves
Performance Objectives 94
Industrial Solenoids 94
Tubular Solenoids 94
Frame Solenoids 94
Applications 97
Solenoids as Electromagnets 97
Solenoid Coils 97
Servicing Coils 97
Solenoid Valves in Circuits 98
Refrigeration Valve 99
Review Questions 100

5 Electric Motors: Selection, Operational Characteristics, and Problems
Performance Objectives 102
Construction of an Induction Motor 102
Single-Phase Motors 103
Shaded-Pole Motor 103
Split-Phase Motor 103
Capacitor-Start Motor 104
Sizes of Motors 104
Cooling and Mounting Motors 105
Direction of Rotation 106
Synchronous Motor 107
Theory of Operation 107
Synchronous Motor Advantages 108
Properties of the Synchronous Motor 108
Electric Motors 109
   Starting the Motor 109
   Repulsion-Induction Motor 110
   Capacitor-Start Motor 111
   Permanent Split-Capacitor Motor 112
   Shaded-Pole Motor 112
   Split-Phase Motor 114
   Polyphase-Motor Starters 115
   Reduced-Voltage Starting Methods 116
     Primary-Resistor Starting 116
     Autotransformer Starting 119
     Part-winding Starting 120
     Wye-delta or Star-delta Starters 121
     Multispeed Starters 123
   Consequent-Pole Motor Controller 124
   Full-Voltage Controllers 127
     Starting Sequence 129
     Protection Against Low Voltage 129
     Time-Delay Protection 129
   Electric Motors: Their Uses, Operation, and Characteristics 132
     Motor Rotation 133
     Variable-Speed Drives 133
   Troubleshooting Electric Motors with a Volt-Ammeter 133
   Split-Core AC Volt-Ammeter 134
     Testing for Grounds 135
     Testing for Opens 135
     Checking for Shorts 136
     Testing Squirrel-Cage Rotors 136
     Testing the Centrifugal Switch in a Split-Phase Motor 136
     Test for Short Circuit Between Run and Start Windings 136
     Test for Capacitors 136
   Using the Megohmmeter for Troubleshooting 138
   Insulation-Resistance Testing 138
     Measuring Insulation Resistance 139
     Power Tools and Small Appliances 139
   Hermetic Compressor Systems 140
     Circuit Breakers and Switches 140
     Coils and Relays 140
   AC Motor Control 140
     Motor Controller 141
     AC Squirrel-Cage Motor 141
       Enclosures 142
       Code 142
       Protection of the Motor 142
     Contactors, Starters, and Relays 142
       Motor-Overload Protector 142
       Motor-Winding Relays 143
   Solenoid Valves 143
   Refrigeration Valve 144
     Application 144
     Operation 144
     Installation 145
     Temperature Controls 145

Bimetallic Thermostats 146
   Thermostat Construction and Wiring 147
Defrost Controls 147
   Defrost Timer Operation 147
   Hot-Gas Defrosting 148
Motor Burnout Cleanup 148
   Procedure for Small Tonnage Systems 148
   Procedure for Large Tonnage Systems 150
Reading a Schematic 150
Review Questions 152

6 Refrigerants: New and Old

   Performance Objectives 156
   Classification of Refrigerants 156
     Common Refrigerants 156
   Freon Refrigerants 158
     Molecular Weights 158
     Flammability 158
     Toxicity 158
     Skin Effects 158
     Oral Toxicity 158
     Central Nervous System (CNS) Effects 159
     Cardiac Sensitization 161
     Thermal Decomposition 162
   Applications of Freon Refrigerants 162
     Reaction of Freon to Various Materials
       Found in Refrigeration Systems 165
       Metals 165
       Plastics 165
   Refrigerant Properties 166
     Pressure 166
     Temperature 166
     Volume 166
     Density 167
     Enthalpy 167
     Flammability 168
     Capability of Mixing with Oil 168
     Moisture and Refrigerants 168
     Odor 168
     Toxicity 169
     Tendency to Leak 169
   Detecting Leaks 169
     Sulfur Dioxide 169
     Carbon Dioxide 169
     Ammonia 170
     Methyl Chloride 170
   Ban on Production and Imports of Ozone-Depleting Refrigerants 170
     Phase-out Schedule for HCFCs, Including R-22 170
     Availability of R-22 171
     Cost of R-22 171
   Alternatives to R-22 171
     Servicing Existing Units 171
     Installing New Units 171
7 Refrigeration Compressors

Performance Objectives 192
Condensers 192
8 Condensers, Chillers, and Cooling Towers

Performance Objectives 242
Condensers 242
Air-Cooled Condensers 242
Water-Cooled Condensers 243
Chillers 246
Refrigeration Cycle 246
Motor-Cooling Cycle 247
Dehydrator Cycle 247
Lubrication Cycle 249
Controls 249
Solid-State Capacity Control 250
Cooling Towers 250
Cooling Systems Terms 251
Design of Cooling Towers 251
Evaporative Condensers 252
New Developments 253
Temperature Conversion 253
Types of Towers 254
Crossflow Towers 254
Fluid Cooler 254
Review Questions 257

9 Working with Water-Cooling Problems

Performance Objectives 260
Pure Water 260
Fouling, Scaling, and Corrosion 260
Prevention of Scaling 261
Scale Identification 262
Field Testing 262
Corrosion 263
Control of Algae, Slime, and Fungi 264
Bacteria 264
The Problem of Scale 265
Evaporative Systems 265
Scale Formation 265
How to Clean Cooling Towers and Evaporative Condensers 266
Determining the Amount of Water in the Sump 266
Determining the Amount of Water in the Tank 266
Total Water Volume 266
Chilled Water Systems 268
How to Clean Shell (Tube or Coil) Condensers 269
Safety 270
Solvents and Detergents 270
Review Questions 270

10 Evaporators

Performance Objectives 274
Coiled Evaporator 274

Application of Controls for Hot-Gas Defrost of Ammonia Evaporators 275
Direct-Expansion Systems 277
Cooling Cycle 277
Direct Expansion with Top Hot-Gas Feed 279
Direct Expansion with Bottom Hot-Gas Feed 279
Flooded Liquid Systems 279
Flooded-gas Leg Shutoff (Bottom Hot-Gas Feed) 279
Flooded-Ceiling Evaporator—Liquid-Leg Shutoff (Bottom Hot-Gas Feed) 280
Flooded-Ceiling Evaporator—Liquid-Leg Shutoff (Top Hot-Gas Feed) 280
Flooded-Ceiling Blower (Top Hot-Gas Feed) 282
Flooded-Ceiling Blower (Hot-Gas Feed through Surge Drum) 283
Flooded Floor-Type Blower (Gas and Liquid-Leg Shutoff) 283
Flooded Floor-Type Blower (Gas Leg Shutoff) 283
Liquid-Recirculating Systems 284
Flooded Recirculator (Bottom Hot-Gas Feed) 285
Flooded Recirculator (Top-Gas Feed) 285
Low-Temperature Ceiling Blower 285
Year-Round Automatic Constant Liquid-Pressure Control System 286
Dual-Pressure Regulator 287
Valves and Controls for Hot-Gas Defrost of Ammonia-Type Evaporators 288
Back-Pressure Regulator Applications of Controls 290
Refrigerant-Powered Compensating-Type Pilot Valve 291
Air-Compensating Back-Pressure Regulator 291
Electric-Compensating Back-Pressure Regulator 292
Valve Troubleshooting 292
Noise in Hot-Gas Lines 297
Review Questions 298

11 Refrigerant: Flow Control

Performance Objectives 300
Metering Devices 300
Hand-Expansion Valve 300
Automatic-Expansion Valve 300
Thermostatic-Expansion Valve 300
Capillary Tubing 301
Float Valve 301
Fittings and Hardware 301
Copper Tubing 301
Contents

12 Servicing and Safety

Performance Objectives 340

Safety 340

Handling Cylinders 340
Pressurizing 340
Working with Refrigerants 341
Lifting 341
Electrical Safety 341

Servicing the Refrigerator Section 341

Sealed Compressor and Motor 342
Condenser 342
Filter Drier 342
Capillary Tube 342
Heat Exchanger 343
Freezer-Compartment and Provision-Compartment Assembly 343

Compressor Replacement 343

Troubleshooting Compressors 343

Troubleshooting Refrigerator Components 343

Compressor Will Not Run 343
Compressor Runs, but There Is No Refrigeration 345
Compressor Short Cycles 345
Compressor Runs Too Much or 100 Percent 345
Noise 346
To Replace the Compressor 346
Compressor Motor Burnout 347
Cleaning System After Burnout 347
Replacing the Filter Drier 347
Replacing the Condenser 349
Replacing the Heat Exchanger 349
Repairing the Perimeter Tube (Fiberglass Insulated) 349
Top-Freezer and Side-by-Side Models 349
Foam-Insulated 12 and 14 ft³ Top-Freezer Models 351
Foam-Insulated 19 ft³ Side-by-Side Models 353
Replacing the Evaporator-Heat Exchanger Assembly 354
Top-Freezer, No-Frost Models 354
Side-by-Side Models 354
Adding Refrigerant 354
Low-Side Leak or Slight Undercharge 355
High-Side Leak or Slight Undercharge 355
Overcharge of Refrigerant 355
Testing for Refrigerant Leaks 355
Service Diagnosis 356
On the Initial Contact 356
Before Starting a Test Procedure 356
Thermostat Cut-Out and Cut-In Temperatures 357
Freezer- and Provision-Compartment Air Temperatures 357
Line Voltage 358
Wattage 358
Compressor Efficiency 358
Refrigerant Shortage 358
Restrictions 359
Defrost-Timer Termination 359
Computing Percent Run Time 359
Start and Run Capacitors 359
Capacitor Ratings 359
Start Capacitor and Bleeder Resistors 360
Run Capacitors 360
Permanent Split-Capacitor (PSC) Compressor Motors 360
Field Testing Hermetic Compressors 361
Warranty Test Procedure 363
Method of Testing 363
Resistance Checks 364
Testing Electrical Components 364
Installing an Air-Cooled Condensing Unit 365
General Information 365
Checking Product Received 365
Corrosive Environment 365
Locating Unit 366
Unit Mounting 366
Refrigerant Connections 368
Replacement Units 368
Evaporator Coil 368
Interconnecting Tubing 368
Suction and Liquid Lines 368
Maximum Length of Interconnecting Tubing 368
Condensing Unit Installed Below Evaporator 368
Condensing Unit Installed Above Evaporator 369
Tubing Installation 370
Tubing Connections 370
Leak Testing 370
Flow-Check Piston 371
Evacuation Procedure 372
Checking Refrigerant Charge 373
Charging by Superheat 373
Charging by Liquid Pressure 373
Charging by Weight 373
Final Leak Testing 374
Service 374
Operation 374
Single-Pole Compressor Contactor (CC) 374
Compressor Crankcase Heat (CCH) 374
Hard Start Components (SC and SR) 374
Time Delay Control (TDC) 374
Low Ambient Control (LAC) 374
High- and Low-Pressure Controls (HPC or LPC) 374
Electrical Wiring 375
Power Wiring 375
Control Wiring 375
Start-up and Performance 376
Troubleshooting 376
Review Questions 377

13 Freezers
Performance Objectives 380
Types of Freezers 380
Installing a Freezer 381
Freezer Components 382
Wrapped Condenser 382
Cold-Ban Trim 382
Shelf Fronts 383
Vacuum Release 383
Lock Assembly 383
Hinges 383
Lid 384
Thermostats 384
Drain System 386
Wrapper Condenser 386
Evaporator Coil 387
Replacing the Compressor 387
Repairing the Condenser 387
Installing the Drier Coil 387
Complete Recharge of Refrigerant 389
Overcharge of Refrigerant 389
Restricted Capillary Tube 389

Contents xi
14 Temperature, Psychrometrics, and Air Control

Performance Objectives 398
Temperature 398
Degrees Fahrenheit 398
Degrees Celsius 398
Absolute Temperature 398
Converting Temperatures 399
Psychrometrics 399
Pressures 399
Gage Pressure 399
Atmospheric Pressure 399
Pressure Measuring Devices 399
Hygrometer 401
Properties of Air 401
People and Moisture 404
Psychrometric Chart 404
Air Movement 404
Convection, Conduction, and Radiation 404
Comfort Conditions 406
Velocity 406
Terminology 408
Designing a Perimeter System 410
Locating and Sizing Returns 411
Airflow Distribution 411
Selection of Diffusers and Grilles 412
Air-Volume Requirement 413
Throw Requirement 413
Pressure Requirement 413
Sound Requirement 414
Casing Radiated Noise 414
Locating Terminal Boxes 414
Controlling Casing Noise 415
Vortex Shedding 415
Return Grilles 415
Performance 415
Return Grille Sound Requirement 416
Types of Registers and Grilles 416
Fire and Smoke Dampers 416
Smoke Dampers for High-Rise Buildings 416
Ceiling Supply Grilles and Registers 416
Ceiling Diffusers 417
Antismudge Rings 418
Air-Channel Diffusers 418
Luminaire Diffusers 418
Room Air Motion 419
Linear Grilles 419
Fans and Mechanical Ventilation 419
Air Volume 419

15 Comfort Air Conditioning

Performance Objectives 428
Window Units 428
Mounting 428
Electrical Plugs 429
Maintenance 430
Low-Voltage Operation 430
Troubleshooting 431
Evaporator Maintenance 431
Automatic Defrosting 431
Evaporators for Add-on Residential Use 433
Troubleshooting 435
Remote Systems 435
Single-Package Rooftop Units 437
Smoke Detectors 437
Firestats 437
Return-Air Systems 438
Acoustical Treatment 438
Volume Dampers 439
Refrigerant Piping 439
Troubleshooting 439
Refrigerant Pipe Sizes 441
Liquid-Line Sizing 441
Suction-Line Sizing 442
Troubleshooting 444
Mobile Homes 444
Troubleshooting 445
Wall-Mounted Ductless Air Conditioners 445
Fan Control Mode 446
Restart Function 447
Rotary Compressor 447
Review Questions 447

16 Commercial Air-Conditioning Systems

Performance Objectives 450
Expansion-Valve Air-Conditioning System 450
Compressor 450
Condenser 450
Expansion-Valve Kit 450
Troubleshooting 450
18 Estimating Load and Insulating Pipes

Performance Objectives 488
Refrigeration and Air-Conditioning Load 488
Running Time 488
Calculating Cooling Load 488
Wall Gain Load 489
Air Change Load 489
Product Load 489
Miscellaneous Loads 489
Calculating Heat Leakage 489
Calculating Product Cooling Load 490
Capacity of the Machines Used in the System 490
Air Doors 491
Insulation 492
Sheet Insulation 492
Tubing Insulation 492
Pipe Insulation 494
Refrigeration Piping 494
Pressure-Drop Considerations 495
Liquid Refrigerant Lines 495
Interconnection of Suction Lines 496
Discharge Lines 496
Water Valves 496
Multiple-Unit Installation 497
Piping Insulation 498
Cork Insulation 498
Rock-Cork Insulation 498
Wool-Felt Insulation 499
Hair-Felt Insulation 499
Review Questions 500

19 Installing and Controlling Electrical Power for Air-Conditioning Units

Performance Objectives 502
Choosing Wire Size 502
Limiting Voltage Loss 502
Minimum Wire Size 502
Wire Selection 502
Wire Size and Low Voltage 502
Voltage Drop Calculations 503
The Effects of Voltage Variations on AC Motors 503
Selecting Proper Wire Size 505
Unacceptable Motor Voltages 505
20 Air-Conditioning and Refrigeration Careers

Performance Objectives 524
Industries that Employ Air-Conditioning and Refrigeration Mechanics 524
Job Qualifications 525
The Future 526
Pay and Benefits 527
Teaching as a Career 528
Sources of Additional Information 528
Review Questions 529

Appendices

A. Some New Refrigerants 531
B. Electrical and Electronic Symbols Used in Schematics 539
C. Programming Thermostats 549
D. Tools of the Trade (Plus Frequently Asked Questions with Answers) 569

Glossary 581
Index 591
Preface

An introduction to the basic principles and practices of the air-conditioning and refrigeration industry is more than just a review of the facts and figures. It requires a complete look at the industry. This text presents the basics of all types of refrigeration. It explains the equipment that makes it possible for us to live comfortably in air-conditioned spaces and enjoy a wide variety of foods.

Up-to-date methods of equipment maintenance are stressed. The latest tools are shown. The applications of the newer types of units are emphasized. The field of air-conditioning technology is still growing and will continue to grow far into the future. New technicians will need to be aware of the fact that change is inevitable. They will have to continue to keep up with the latest developments as long as they stay in the field.

This textbook has been prepared to aid in instructional programs in high schools, technical schools, trade schools, and community colleges. Adult evening classes and apprenticeship programs may also find it useful. This book provides a thorough knowledge of the basics and a sound foundation for anyone entering the air-conditioning and refrigeration field.

The authors would like to give a special thanks to Mr. Burt Wallace who is an instructor in the air conditioning and refrigeration program in Tyler Junior College and Mr. Andy Bugg an AC Applications Engineer for one of the largest air conditioning manufacturers for their most valuable contributions to the book. Both live in Tyler, Texas.

Rex Miller
Mark R. Miller
Acknowledgments

No author works without being influenced and aided by others. Every book reflects this fact. This book is no exception. A number of people cooperated in providing technical data and illustrations. For this we are grateful.

We would like to thank those organizations that so generously contributed information and illustrations. The following have been particularly helpful:

Admiral Group of Rockwell International
Air Conditioning and Refrigeration Institute
Air Temp Division of Chrysler Corp.
AmeriCold Compressor Corporation
Amprobe Instrument Division of SOS Consolidated, Inc.
Arkla Industries, Inc.
Bryant Manufacturing Company
Buffalo News
Calgon Corporation
Carrier Air Conditioning Company
E.I. DuPont de Nemours & Co., Inc.
Dwyer Instruments, Inc.
Ernst Instruments, Inc.
General Controls Division of ITT
General Electric Co. (Appliance Division)
Haws Drinking Faucet Company
Hubbell Corporation
Hussman Refrigeration, Inc.
Johnson Controls, Inc.
Karl-Kold, Inc.

Kodak Corporation
Lennox Industries, Inc.
Lima Register Co.
Marley Company
Marsh Instrument Company, Division of General Signal
Mitsubishi Electric, HVAC Advanced Products Division
Mueller Brass Company
National Refrigerants
Packless Industries, Inc.
Parker-Hannifin Corporation
Penn Controls, Inc.
Rheem Manufacturing Company
Schaefer Corporation
Sears, Roebuck and Company
Snap-on Tools, Inc.
Sporlan Valve Company
Superior Electric Company
Tecumseh Products Company
Thermal Engineering Company
Trane Company
Turner Division of Clean-weld Products, Inc.
Tuttle & Bailey Division of Allied Thermal Corporation
Tyler Refrigeration Company
Union Carbide Company, Linde Division
Universal-Nolin Division of UMC Industries, Inc.
Virginia Chemicals, Inc.
Wagner Electric Motors
Weksler Instrument Corporation
Westinghouse Electric Corp.
Worthington Compressors
ABOUT THE AUTHORS

**Rex Miller** is Professor Emeritus of Industrial Technology at State University College at Buffalo and has taught technical curriculum at the college level for more than 40 years. He is the coauthor of the best-selling *Carpentry & Construction*, now in its fourth edition, and the author of more than 80 texts for vocational and industrial arts programs. He lives in Round Rock, Texas.

**Mark R. Miller** is Professor of Industrial Technology at the University of Texas at Tyler. He teaches construction courses for future middle managers in the trade. He is coauthor of several technical books, including the best-selling *Carpentry & Construction*, now in its fourth edition. He lives in Tyler, Texas.
Air Conditioning and Refrigeration
1 CHAPTER

Air-Conditioning and Refrigeration Tools and Instruments
PERFORMANCE OBJECTIVES
After studying this chapter the reader should be able to:

1. Understand how tools and instruments make it possible to install, operate, and troubleshoot air-conditioning and refrigeration equipment.
2. Know how electricity is measured.
3. Know how to use various tools specially made for air-conditioning and refrigeration work.
4. Know how to identify by name the tools used in the trade.
5. Know the difference between volt, ampere, and ohm and how to measure each.
6. Know how to work with air-conditioning and refrigeration equipment safely.

TOOLS AND EQUIPMENT
The air-conditioning technician must work with electricity. Equipment that has been wired may have to be replaced or rewired. In any case, it is necessary to identify and use safely the various tools and pieces of equipment. Special tools are needed to install and maintain electrical service to air-conditioning units. Wires and wiring should be installed according to the National Electrical Code (NEC). However, it is possible that this will not have been done. In such a case, the electrician will have to be called to update the wiring to carry the extra load of the installation of new air-conditioning or refrigeration equipment.

This section deals only with interior wiring. Following is a brief discussion of the more important tools used by the electrician in the installation of air-conditioning and refrigeration equipment.

Pliers and Clippers
Pliers come in a number of sizes and shapes designed for special applications. Pliers are available with either insulated or uninsulated handles. Although pliers with insulated handles are always used when working on or near “hot” wires, they must not be considered sufficient protection alone. Other precautions must be taken. Long-nose pliers are used for close work in panels or boxes. Slip-joint, or gas, pliers are used to tighten locknuts or small nuts. See Fig. 1-1. Wire cutters are used to cut wire to size.

Fuse Puller
The fuse puller is designed to eliminate the danger of pulling and replacing cartridge fuses by hand, Fig. 1-2.

It is also used for bending fuse clips, adjusting loose cutout clips, and handling live electrical parts. It is made of a phenolic material, which is an insulator. Both ends of the puller are used. Keep in mind that one end is for large-diameter fuses; the other is for small-diameter fuses.

Screwdrivers
Screwdrivers come in many sizes and tip shapes. Those used by electricians and refrigeration technicians should have insulated handles. One variation of the screwdriver is the screwdriver bit. It is held in a brace and used for heavy-duty work. For safe and efficient use, screwdriver tips should be kept square and sharp. They should be selected to match the screw slot. See Fig. 1-3.

The Phillips-head screwdriver has a tip pointed like a star and is used with a Phillips screw. These
screws are commonly found in production equipment. The presence of four slots, rather than two, assures that the screwdriver will not slip in the head of the screw. There are a number of sizes of Phillips-head screwdrivers. They are designated as No. 1, No. 2, and so on. The proper point size must be used to prevent damage to the slot in the head of the screw. See Fig. 1-4.

Wrenches
Three types of wrenches used by the air-conditioning and refrigeration trade are shown in Fig. 1-5.

• The adjustable open-end wrenches are commonly called crescent wrenches.
• Monkey wrenches are used on hexagonal and square fittings such as machine bolts, hexagonal nuts, or conduit unions.
• Pipe wrenches are used for pipe and conduit work. They should not be used where crescent or monkey wrenches can be used. Their construction will not permit the application of heavy pressure on square or hexagonal material. Continued misuse of the tool in this manner will deform the teeth on the jaw face and mar the surfaces of the material being worked.

Soldering Equipment
The standard soldering kit used by electricians consists of the same equipment that the refrigeration mechanics use. See Fig. 1-6. It consists of a nonelectric soldering device in the form of a torch with propane fuel cylinder or an electric soldering iron, or both.

The torch can be used for heating the solid-copper soldering iron or for making solder joints in copper tubing. A spool of solid tin-lead wire solder or flux-core

Fig. 1-4 A Phillips-head screwdriver.

Fig. 1-5 Wrenches. (A) Crescent wrench. (B) Pipe wrench. (C) Using a monkey wrench.

Fig. 1-6 Soldering equipment.
solder is used. Flux-core solder with a rosin core is used for electrical soldering.

Solid-core solder is used for soldering metals. It is strongly recommended that acid-core solder not be used with electrical equipment. Soldering paste is used with the solid wire solder for soldering joints on copper pipe or solid material. It is usually applied with a small stiff-haired brush.

**Drilling Equipment**

Drilling equipment consists of a brace, a joint-drilling fixture, an extension bit to allow for drilling into and through thick material, an adjustable bit, and a standard wood bit. These are required in electrical work to drill holes in building structures for the passage of conduit or wire in new or modified construction.

Similar equipment is required for drilling holes in sheet-metal cabinets and boxes. In this case, high-speed or carbide-tipped drills should be used in place of the carbon-steel drills that are used in wood drilling. Electric power drills are also used. See Fig. 1-7.

They are also used in the construction of wood-panel mounting brackets. The keyhole saw will again be used when cutting an opening in a wall of existing buildings where boxes are to be added or tubing is to be inserted for a refrigeration unit.

**Woodworking Tools**

Crosscut saws, keyhole saws, and wood chisels are used by electricians and refrigeration and air-conditioning technicians. See Fig. 1-8. They are used to remove wooden structural members, obstructing a wire or conduit run, and to notch studs and joists to take conduit, cable, box-mounting brackets, or tubing.

**Metalworking Tools**

The cold chisel and center punch are used when working on steel panels. See Fig. 1-9. The knockout punch is used either in making or in enlarging a hole in a steel cabinet or outlet box.

The hacksaw is usually used when cutting conduit, cable, or wire that is too large for wire cutters. It is also a handy device for cutting copper tubing or pipe. The mill file is used to file the sharp ends of such cutoffs. This is a precaution against short circuits or poor connections in tubing.

**Masonry Working Tools**

The air-conditioning technician should have several sizes of masonry drills in the tool kit. These drills normally are carbide-tipped. They are used to drill holes in brick or concrete walls. These holes are used for anchoring apparatus with expansion screws or for allowing the passage of conduit, cable, or tubing. Figure 1-10 shows the carbide-tipped bit used with a power drill and a hand-operated masonry drill.
Knives and Other Insulation-Stripping Tools

The stripping or removing of wire and cable insulation is accomplished by the use of tools shown in Fig. 1-11. The knives and patented wire strippers are used to bare the wire of insulation before making connections. The scissors are used to cut insulation and tape.

The armored cable cutter may be used instead of a hacksaw to remove the armor from the electrical conductors at box entry or when cutting the cable to length.

Hammers Hammers are used either in combination with other tools, such as chisels, or in nailing equipment to building supports. See Fig. 1-12. The figure shows a carpenter’s claw hammer and a machinist’s ball-peen hammer.

Tape Various tapes are available. They are used for replacing removed insulation and wire coverings.
Friction tape is a cotton tape impregnated with an insulating adhesive compound. It provides weather resistance and limited mechanical protection to a splice already insulated.

Rubber tape or varnished cambric tape may be used as an insulator when replacing wire covering.

Plastic electrical tape is made of a plastic material with an adhesive on one side of the tape. It has replaced friction and rubber tape in the field for 120- and 208-V circuits. It serves a dual purpose in taping joints. It is preferred over the former tapes.

Ruler and Measuring Tape The technician should have a folding rule and a steel tape. Both of these are aids to cutting to exact size.

Extension Cord and Light The extension light shown in Fig. 1-13, is normally supplied with a long extension cord. It is used by the technician when normal building lighting has not been installed and where the lighting system is not functioning.

Wire Code Markers Tapes with identifying numbers or nomenclature are available for permanently identifying wires and equipment. The wire code markers are particularly valuable for identifying wires in complicated wiring circuits, in fuse boxes, and circuit breaker panels, or in junction boxes. See Fig. 1-14.

Meters and Test Prods
An indicating voltmeter or test lamp is used when determining the system voltage. It is also used in locating the ground lead and for testing circuit continuity through the power source. They both have a light that glows in the presence of voltage. See Fig. 1-15.

A modern method of measuring current flow in a circuit uses the hook-on voltammeter. See Fig. 1-16. This instrument does not have to be hooked into the
An ohmmeter is used. The ohmmeter uses leads to complete the circuit to the device under test.

Use of the voltammeter is a quick way of testing the air-conditioning or refrigeration unit motor that is drawing too much current. A motor that is drawing too much current will overheat and burn out.

**Tool Kits**

Some tool manufacturers make up tool kits for the refrigeration and appliance trade. See Fig. 1-17 for a good example. In the Snap-on tool kit, the leak detector is part of the kit. The gages are also included. An adjustable wrench, tubing cutter, hacksaw, flaring tool, and ball-peen hammer can be hung on the wall and replaced when not in use. One of the problems for any repairperson is keeping track of tools. Markings on a board will help locate at a glance when one is missing.

Figure 1-18 shows a portable tool kit. Figure 1-18J shows a pulley puller. This tool is used to remove the circuit. It can be operated with comparative ease. Just remember that it measures only one wire. Do not clamp it over a cord running from the consuming device to the power source. In addition, this meter is used only on **alternating current** (AC) circuits. The AC current will cancel the reading if two wires are covered by the clamping circle. Note how the clamp-on part of the meter is used on one wire of the motor.

To make a measurement, the hook-on section is opened by hand and the meter is placed against the conductor. A slight push on the handle snaps the section shut. A slight pull on the handle springs open the tool on the C-shaped current transformer and releases a conductor. Applications of this meter are shown in Fig. 1-16. Figure 1-16B shows current being measured by using the hook-on section. Figure 1-16C shows the voltage being measured using the meter leads. An ohmmeter is included in some of the newer models. However, power in the circuit must be off when the ohmmeter is used. The ohmmeter uses leads to complete the circuit to the device under test.

Use of the voltammeter is a quick way of testing the air-conditioning or refrigeration unit motor that is drawing too much current. A motor that is drawing too much current will overheat and burn out.
Fig. 1-17 Refrigeration and appliance tools. (A) Servicing manifold. (B) Ball-peen hammer. (C) Adjustable wrench. (D) Tubing tapper. (E) Tape measure. (F) Allen wrench set. (G) 90° adapter service part. (H) Tubing cutter. (I) Thermometer. (J) Flaring tool kit. (K) Knife. (L) Hacksaw. (M) Jab saw. (N) Halide leak detector. (Snap-On Tools)

Fig. 1-18 Air-conditioning and refrigeration portable tool kit. (A) Air-conditioning charging station. (B) Excavating/charging valve. (C) 90 adapter service port. (D) O-ring installer. (E) Refrigeration ratchet. (F) Snap-ring pliers. (G) Stem thermometer. (H) Seal remover and installer. (I) Test light. (J) Puller. (K) Puller jaws. (L) Retainer ring pliers. (M) Refrigerant can tapper. (N) Dipsticks for checking oil level. (O) Halide leak detector. (P) Flexible charging hose. (Q) Goggles. (Snap-On Tools)
GAGES AND INSTRUMENTS

It is impossible to install or service air-conditioning and refrigeration units and systems without using gages and instruments.

A number of values must be measured accurately if air-conditioning and refrigeration equipment is to be operated properly. Refrigeration and air-conditioning units must be properly serviced and monitored if they are to give the maximum efficiency for the energy expended. Here, the use of gages and instruments becomes important. It is not possible to analyze a system’s operation without the proper equipment and procedures. In some cases, it takes thousands of dollars worth of equipment to troubleshoot or maintain modern refrigeration and air-conditioning system.

Instruments are used to measure and record such values as temperature, humidity, pressure, airflow, electrical quantities, and weight. Instruments and monitoring tools can be used to detect incorrectly operating equipment. They can also be used to check efficiency. Instruments can be used on a job, in the shop, or in the laboratory. If properly cared for and correctly used, modern instruments are highly accurate.

Pressure Gages

Pressure gages are relatively simple in function. See Fig. 1-21. They read positive pressure or negative pressure, or both. See Fig. 1-22. Gage components are

Fig. 1-19 AC and DC voltage probe voltmeter. (Amprobe)

Fig. 1-20 Voltage and current recorder. (Amprobe)
relatively few. However, different combinations of gage components can produce literally millions of design variations. See Fig. 1-23. One gage buyer may use a gage with 0 to 250 psi range, while another person with the same basic measurement requirements will order a gage with a range of 0 to 300 psi. High-pressure gages can be purchased with scales of 0 to 1000, 2000, 3000, 4000, or 5000 psi.

There are, of course, many applications that will continue to require custom instruments, specially designed and manufactured. Most gage manufacturers have both stock items and specially manufactured gages.

**Gage Selection**

Since 1939, gages used for pressure measurements have been standardized by the American National Standards Institute (ANSI). Most gage manufacturers are consistent in face patterns, scale ranges, and grades of accuracy. Industry specifications are revised and updated periodically.

Gage accuracy is stated as the limit that error must not exceed when the gage is used within any combination of rated operating conditions. It is expressed as a percentage of the total pressure (dial) span.

Classification of gages by ANSI standards has a significant bearing on other phases of gage design and specification. As an example, a test gage with ±0.25 percent accuracy would not be offered in a 2 in. dial size. Readability of smaller dials is not sufficient to permit the precision indication necessary for this degree of accuracy. Most gages with accuracy of ±0.5 percent and better have dials that are at least 4.5 in. Readability can be improved still further by increasing the dial size.

**Accuracy** How much accuracy is enough? This is a question only the application engineer can answer. However, from the gage manufacturer’s point of view, increased accuracy represents a proportionate increase in the cost of building a gage. Tolerances of every component must be more exacting as gage accuracy increases.
Time is needed for technicians to calibrate the gage correctly. A broad selection of precision instruments is available and grades A (±1 percent), 2A (±0.5 percent), and 3A (±0.25 percent) are examples of tolerances available.

With the advent of modern electronic gages and more sophisticated equipment it is possible to obtain heretofore undreamed of accuracy automatically with equipment used in the field.

**Medium** In every gage selection, the medium to be measured must be evaluated for potential corrosiveness to the Bourdon tube of the gage.

There is no ideal material for Bourdon tubes. No single material adapts to all applications. Bourdon tube materials are chosen for their elasticity, repeatability, ability to resist “set” and corrosion resistance to the fluid mediums.

Ammonia refrigerants are commonly used in refrigeration. All-steel internal construction is required. Ammonia gages have corresponding temperature scales. A restriction screw protects the gage against sudden impact, shock, or pulsating pressure. A heavy-duty movement of stainless steel and Monel steel prevents corrosion and gives extra-long life. The inner arc on the dial shows pressure. The other arc shows the corresponding temperature. See Fig. 1-24.

**Line Pressure**

The important consideration regarding line pressures is to determine whether the pressure reading will be constant or whether it will fluctuate. The maximum pressure at which a gage is continuously operated should not exceed 75 percent of the full-scale range. For the best performance, gages should be graduated to twice the normal system-operating pressure.

This extra margin provides a safety factor in preventing overpressure damage. It also helps avoid a permanent set of the Bourdon tube. For applications with substantial pressure fluctuations, this extra margin is especially important. In general, the lower the Bourdon tube pressure, the greater the overpressure percentage it will absorb without damage. The higher the Bourdon tube pressure, the less overpressure it will safely absorb.

Pulsation causes pointer flutter, which makes gage reading difficult. Pulsation also can drastically shorten gage life by causing excessive wear of the movement gear teeth. A pulsating pressure is defined as a pressure variation of more than 0.1 percent full-scale per second. Following are conditions often encountered and suggested means of handling them.

The restrictor is a low-cost means of combating pulsation problems. This device reduces the pressure opening. The reduction of the opening allows less of the pressure change to reach the Bourdon tube in a given time interval. This dampening device protects the Bourdon tube by the retarding overpressure surges. It also improves gage readability by reducing pointer flutter. When specifying gages with restrictors, indicate whether the pressure medium is liquid or gas. The medium determines the size of the orifice. In addition, restrictors are not recommended for dirty line fluids. Dirty materials in the line can easily clog the orifice. For such conditions, diaphragm seals should be specified.

The needle valve is another means of handling pulsation if used between the line and the gage. See Fig. 1-25. The valve is throttled down to a point where pulsation ceases to register on the gage.

In addition, to the advantage of precise throttling, needle valves also offer complete shutoff, an important safety factor in many applications. Use of a needle valve can greatly extend the life of the gage by allowing it to be used only when a reading is needed.

Liquid-filled gages are another very effective way to handle line pulsation problems. Because the movement is constantly submerged in lubricating fluid, reaction to pulsating pressure is dampened and the pointer flutter is practically eliminated.

Silicone-oil-treated movements dampen oscillations caused by line pressure pulsations and/or mechanical oscillation. The silicone oil, applied to the movement, bearings, and gears, acts as a shock absorber.

**Fig. 1-24** Ammonia gage. (Marsh)
This extends the gage life while helping to maintain accuracy and readability.

**Effects of Temperature on Gage Performance**

Because of the effects of temperature on the elasticity of the tube material, the accuracy may change. Gages calibrated at 75°F (23.9°C) may change by more than 2 percent at:

- *Full scale* (FS) below −30°F (−34°C)
- Above 150° F (65.6°C)

**Care of Gages**

The pressure gage is one of the service person’s most valuable tools. Thus, the quality of the work depends on the accuracy of the gages used. Most are precision-made instruments that will give many years of dependable service if properly treated.

The test gage set should be used primarily to check pressures at the low and high side of the compressor. The ammonia gage should be used with a steel Bourdon tube tip and socket to prevent damage.

Once you become familiar with the construction of your gages, you will be able to handle them more efficiently. The internal mechanism of a typical gage is shown in Fig. 1-23. The internal parts of a vapor tension thermometer are very similar.

Drawn brass is usually used for case material. It does not corrode. However, some gages now use high-impact plastics. A copper alloy Bourdon tube with a brass tip and socket is used for most refrigerants. Stainless steel is used for ammonia. Engineers have found that moving parts involved in rolling contact will last longer if made of unlike metals. That is why many top-grade refrigeration gages have bronze-bushed movements with a stainless steel pinion and arbor.

The socket is the only support for the entire gage. It extends beyond the case. The extension is long enough to provide a wrench flat enough for use in attaching the gage to the pressure source. Never twist the case when threading the gage into the outlet. This could cause misalignment or permanent damage to the mechanism.

NOTE: Keep gages and thermometers separate from other tools in your service kit. They can be knocked out of alignment by a jolt from a heavy tool.

Most pressure gages for refrigeration testing have a small orifice restriction screw. The screw is placed in the pressure inlet hole of the socket. It reduces the effects of pulsations without throwing off pressure readings. If the orifice becomes clogged, the screw can be easily removed for cleaning.

**Gage Recalibration**

Most gages retain a good degree of accuracy in spite of daily usage and constant handling. Since they are precision instruments, however, you should set up a regular program for checking them. If you have a regular
If remote readings are necessary, then the vapor tension thermometer is best. It has a closed, filled Bourdon tube. A bulb is at one end for temperature sensing. Changes in the temperature at the bulb result in pressure changes in the fill medium. Remote reading thermometers are equipped with 6 ft of capillary tubing as standard. Other lengths are available on special order.

The location of direct or remote reading is important when choosing a thermometer. Four common types of thermometers are used to measure temperature:

- Pocket thermometer
- Bimetallc thermometer
- Thermocouple thermometer
- Resistance thermometer

Pocket Thermometer

The pocket thermometer depends upon the even expansion of a liquid. The liquid may be mercury or colored alcohol. This type of thermometer is versatile. It can be used to measure temperatures of liquids, air, gas, and solids. It can be strapped to the suction line during a superheat measurement. For practical purposes, it can operate wet or dry. This type of thermometer can withstand extremely corrosive solutions and atmospheres.

If your gage has a recalibrator screw on the face of the dial, as in Fig. 1-26, remove the ring and glass. Relieve all pressure to the gage. Turn the recalibration screw until the pointer rests at zero.

The gage will be as accurate as when it left the factory if it has a screw recalibration adjustment. Resetting the dial to zero restores accuracy throughout the entire range of dial readings.

If you cannot calibrate the gage by either of these methods, take it to a qualified specialist for repair.
The greatest error in the use of the glass thermometer is that it is often not read in place. It is removed from the outlet grille of a packaged air conditioner. Then it is carried to eye level in the room at ambient temperatures. Here it is read a few seconds to a minute later. It is read in a temperature different from that in which it was measured.

A liquid bath temperature reading is taken with the bulb in the bath. It is then left for a few minutes, immersed, and raised so that it can be read.
is always rough handling. Such handling cannot be avoided at all times in service work. Splitting does not occur in thermometers that do not have a gas atmosphere over the mercury. Such thermometers allow the mercury to move back and forth by gravity, as well as temperature change. Such thermometers may not be used in other than vertical positions.

A split thermometer can be repaired. Most service thermometers have the mercury reservoir at the bottom of the tube. In this case, cool the thermometer bulb in shaved ice. This draws the mercury to the lower part of the reservoir. Add more ice or salt to lower the temperature, if necessary. With the thermometer in an upright position, tap the bottom of the bulb on a padded piece of paper or cloth. The entrapped gas causing the split column should then rise to the top of the mercury. After the column has been joined, test the service thermometer against a standard thermometer. Do this at several service temperatures.

**Bimetallic Thermometers**

Dial thermometers are actuated by bimetallic coils, mercury, vapor pressure, or gas. They are available in varied forms that allow the dial to be used in a number of locations. See Fig. 1-29. The sensing portion of the instrument may be located somewhere else. The dial can be read in a convenient location.

Bimetallic thermometers have a linear dial face. There are equal increments throughout any given dial ranges. Dial ranges are also available to meet higher temperature measuring needs. Ranges up to 1000°F (537.8°C) are available. In four selected ranges, dials giving both Celsius and Fahrenheit readings are available. Bimetallic thermometers are economical. There is no need for a machined movement or gearing. The temperature-sensitive bimetallic element is connected directly to the pointer. This type of thermometry is well adapted to measuring the temperature of a surface. Dome-mounted thermal protectors actually react to the surface temperature of the compressor skin. These thermometers are used where direct readings need to be taken, such as on:

- Pipelines
- Tanks
- Ovens
- Ducts
- Sterilizers
- Heat exchangers
- Laboratory temperature baths
The simplest type of dial thermometer is a stem. The stem is inserted into the medium to be measured. With the stem immersed 2 in. in liquids and 4 in. in gases, this thermometer gives reasonably accurate readings.

Although dial thermometers have many uses, there are some limitations. They are not as universally applicable as the simple glass thermometer. When ordering a dial thermometer, specify the stem length, scale range, and medium in which it will be used.

One of the advantages of bimetallic thermometry is that the thermometer can be applied directly to surfaces. It can be designed to take temperatures of pipes from 0.5 through 2 in.

In operation, the bimetallic spiral is closely coupled to the heated surface that is to be measured. The thermometer is held fast by two permanent magnets. One manufacturer claims their type of thermometer reaches stability within 3 min. Its accuracy is said to be plus or minus 2 percent in working ranges.

A simple and inexpensive type of bimetallic thermometer scribes temperature travel on a load of food in transit. It can be used also to check temperature variations in controlled industrial areas. The replacement chart gives a permanent record of temperature variations during the test period.

Bimetallic drives are also used in control devices. For example, thermal overload sensors for motors and other electrical devices use bimetallic elements. Other examples will be discussed later.

**Thermocouple Thermometers**

Thermocouples are made of two dissimilar metals. Once the metals are heated, they give off an EMF (electromotive force or voltage). This electrical energy can be measured with a standard type of meter designed to measure small amounts of current. The meter can be calibrated in degrees, instead of amperes, milliamperes, or microamperes.

In use, the thermocouples are placed in the medium that is to be measured. Extension wires run from the thermocouple to the meter. The meter then gives the temperature reading at the remote location.

The extension wires may be run outside closed chests and rooms. There is no difficulty in closing a door, and the wires will not be pinches. On air-conditioning work, one thermocouple may be placed in the supply grille and another in the return grille. Readings can be taken seconds apart without handling a thermometer.

Thermocouples are easily taped onto the surface of pipes to check the inside temperature. It is a good idea to insulate the thermocouple from ambient and radiated heat. Although this type of thermometer is rugged, it should be handled with care. It should not be handled roughly. Thermocouples should be protected from corrosive chemicals and fumes. Manufacturer’s instructions for protection and use are supplied with the instrument.

**Resistance Thermometers**

One of the newer ways to check temperature is with a thermometer that uses a resistance-sending element. An electrical sensing unit may be made of a thermistor. A thermistor is a piece of material that changes resistance rapidly when subjected to temperature changes. When heated, the thermistor lowers its resistance. This decrease in resistance makes a circuit increase its current. A meter can be inserted in the circuit. The change in current can be calibrated against a standard thermometer. The scale can be marked to read temperature in degrees Celsius or degrees Fahrenheit.

Another type of resistance thermometer indicates the temperature by an indicating light. The
Preventing kinks in the capillary is important. Keep the capillary clean by removing grease and oil. Clean the case and crystal with a mild detergent.

**Superheat Thermometer**

The superheat thermometer is used to check for correct temperature differential of the refrigerator gas. The inlet and outlet side of the evaporator coil have to be measured to obtain the two temperatures. The difference is obtained by subtracting.

Test thermometers are available in boxes. See Fig. 1-30. The box protects the thermometer. It is important to keep the thermometer in operating condition. Several guidelines must be followed. Figure 1-31 illustrates how to keep the test thermometer in good working condition.

**Superheat Measurement Instruments**

Superheat plays an important role in refrigeration and air-conditioning service. For example, the thermostatic expansion valve operates on the principle of superheat. In charging capillary tube systems, the superheat measurement must be carefully watched. The suction line superheat is an indication of whether the liquid refrigerant is flooding the compressor from the suction side. A measurement of zero superheat is a definite indicator that liquid is reaching the compressor. A measurement of 6 to 10°F (−14.4 to −12.2°C) for the expansion valve system and 20°F (6.7°C) for capillary tube system indicates that all refrigerant is vaporized before entering the compressor.

The superheat at any point in a refrigeration system is found by first measuring the actual refrigerant temperature at that point using an electronic thermometer. Then the boiling point temperature of the refrigerant is found by connecting a compound pressure gage to the system and reading the boiling temperature from the center of the pressure gage. The difference between the actual temperature and the boiling point temperature is superheat. If the superheat is zero, the refrigerant must be boiling inside. Then, there is a good chance that some of the refrigerant is still liquid. If the superheat is greater than zero, by at least 5°F or better, then the refrigerant is probably past the boiling point stage and is all vapor.

The method of measuring superheat described here has obvious faults. If there is no attachment for a pressure gage at the point in the system where you are measuring superheat, the hypothetical boiling temperature cannot be found. To determine the superheat at such a point, the following method can be used. This method is particularly useful for measuring the refrigerant superheat in the suction line.

Instead of using a pressure gage, the boiling point of the refrigerant in the evaporator can be determined by measuring the temperature in the line just after the expansion valve where the boiling is vigorous. This can be done with any electronic thermometer. See Fig. 1-32. As the refrigerant heats up through the evaporator and the suction line, the actual temperature of the refrigerant can be measured at any point along the suction line. Comparison of these two temperatures gives a superheat measurement sufficient for field service.
KEEP YOUR THERMOMETERS WORKING BY FOLLOWING THESE STEPS

1. DO NOT CUT, TWIST, OR KINK CAPILLARY.
   When capillary becomes kinked, remove the kink by carefully bending the capillary in a direction opposite to the kink.
   To straighten twisted capillary, grasp the tubing in both hands and untwist short sections at a time, being careful not to break the fine wire armor.
   Cutting the capillary will release the charge and render the instrument useless.

2.REWIND CAPILLARY CAREFULLY IN CLOCKWISE DIRECTION.
   Allow bulb to hang free and turn with winding.
   Keep bulb in holding clip when thermometer is not in use. Clip will turn in any direction to receive bulb.

3. UNREEL CAPILLARY CAREFULLY AND PLACE IN SLOT AT SIDE OF CASE BEFORE CLOSING.

4. DO NOT BEND OR FLATTEN BULB.
   Distortion of the bulb will result in false reading.

5. DO NOT TWIST CAPILLARY AROUND BULB TO HOLD IN POSITION.
   A small piece of tape will usually be adequate to hold bulb in place.

6. TO CLEAN CASE AND CRYSTAL, USE A MILD DETERGENT AND SOFT RAG.

7. TO CLEAN OIL OR GREASE FROM CAPILLARY OR BULB, DIP IN CARBON TETRACHLORIDE AND WIPE WITH SOFT RAG.

8. MAGNETIC BASE UNIT USED FOR CONVENIENT POSITION MOUNTING OF THERMOMETER.

Fig. 1-31 How to take care of the thermometer? (Marsh)
unless a distributor-metering device is used or the evaporator is very large with a great amount of pressure drop across the evaporator.

By using the meter shown in Fig. 1-33, it is possible to read superheat directly, using the temperature differential feature. Strap one end of the differential probe to the outlet of the metering device. Strap the other end to the point on the suction line where the superheat measure is to be taken. Turn the meter to temperature differential and the superheat will be directly read on the meter.

Figure 1-34 illustrates the way superheat works. The bulb “opening” force (F-1) is caused by bulb temperature. This force is balanced against the system back-pressure (F-2) and the valve spring force (F-3). The force holds the evaporator pressure within a range that will vaporize the entire refrigerant just before it reaches the upper part or end of the evaporator.

The method of checking superheat is shown in Fig. 1-35. The procedure is as follows:

Fig. 1-32  Hand-held electronic thermometer. (Amprobe)

Fig. 1-33  Electronic thermometer for measuring superheat. The probes are made of thermo-couple wire. They can be strapped on anywhere with total contact with the surface. This thermometer covers temperatures from –50°F to 1500°F on four scales. The temperature difference between any two points directly means it can read superheat directly. It is battery operated and has a ±2 percent accuracy on all ranges. Celsius scales are available. (Thermal Engineering)
1. Measure the temperature of the suction line at the bulb location. In the example, the temperature is 37°F.

2. Measure the suction line pressure. In the example, the suction line pressure is 27 psi.

3. Convert the suction line pressure to the equivalent saturated (or liquid) evaporator temperature by using a standard temperature-pressure chart (27 psi = 28°F).

4. Subtract the two temperatures. The difference is superheat. In this case, superheat is found by the formula: 37°F – 28°F = 9°F

Suction pressure at the bulb may be obtained by either of the following methods:

- If the valve has an external equalizer line, the gage in this line may be read directly.

- If the valve is internally equalized, take a pressure gage reading at the compressor base valve. Add to this the estimated pressure drop between the gage and the bulb location. The sum will approximate the pressure at the bulb.
The system should be operating normally when the superheat is between 6 and 10°F (−14.4 and −12.2°C).

**HALIDE LEAK DETECTORS**

Not too long ago leaks were detected by using soap bubbles and water. If possible, the area of the suspected leak was submerged in soap water. Bubbles pinpointed the leak area. If the unit or suspected area was not easily submerged in water then it was coated with soap solution. In addition, where the leak was covered with soap, bubbles would be produced. These indicated the location of the leak. These methods are still used today in some cases. However, it is now possible to obtain better indications of leaks with electronic equipment with halide leak detectors.

Halide leak detectors are used in the refrigeration and air-conditioning industry. They are designed for locating leaks and noncombustible halide refrigerant gases. See Figs. 1-36 and 1-37.

The supersensitive detector will detect the presence of as little as 20 parts per million of refrigerant gases. See Fig. 1-38. Another model will detect 100 parts of halide gas per million parts of air.

**Setting Up**

The leak detector is normally used with a standard torch handle. The torch handle has a shut-off valve. Acetylene can be supplied by a “B” tank (40 ft³) or MC tank (10 ft³). In either case, the tank must be equipped with a pressure-reducing regulator; the torch handle is connected to the regulator by a suitable length of fitted acetylene hose. See Fig. 1-36.
An alternate setup uses an adapter to connect the leak detector stem to an MC tank. No regulator is required. The tank must be fitted with a handle. See Fig. 1-37.

In making either setup, be sure all seating sources are clean before assembling. Tighten all connections securely. Use a wrench to tighten hose and regulator connections. If you use the "B" tank setup, be sure to follow the instructions supplied with the torch handle and regulator.

**Lighting**

Setup with tank, regulator, and torch handle. Refer to Fig. 1-36.
- Open the tank valve one-quarter turn, using a P-O-L tank key.
- Be sure the shut-off valve on the torch handle is closed. Then, adjust the regulator to deliver 10 psi. Do this by turning in the pressure-adjusting screw until the "C" marking on the flat surfaces of the screw is opposite the face of the front cap. Test for leaks.
- Open the torch handle shut-off valve and light the gas above the reaction plate. Use a match or taper.
- Adjust the torch until a steady flame is obtained.

Setup with MC tank and adaptor. Refer to Fig. 1-37.
- With the needle valve on the adaptor closed tightly, just barely open the tank valve, using a P-O-L tank key. Test for leaks.
- Open the adapter needle valve about one-quarter turn. Light the gas above the reaction plate. Use a match or taper.

**Leak Testing the Setup**

Using a small brush, apply a thick solution of soap and water to test for leaks. Check for leaks at the regulator and any connection point. Check the hose to handle connection, hose to regulator connection, and regulator or adaptor connection. If you find a leak, correct it before you light the gas. A leak at the valve stem of a small acetylene tank can often be corrected by tightening the packing nut with a wrench. If this will not stop a leak, remove the tank. Tag it to indicate valve stem leakage. Place it outdoors in a safe spot until you can return it to the supplier.

**Adjusting the Flame**

Place the inlet end of the suction hose so that it is unlikely to draw in air to contaminate the refrigerant vapor. Adjust the needle valve on the adapter or torch handle until the pale blue outer envelope of the flame extends about 1 in. above the reaction plate. The inner cone of the flame, which should also be visible above the reaction plate, should be clear and sharply defined.

If the outer envelope of the flame, when of proper length, is yellow, not pale blue, the hose is picking up refrigerant vapors. There may also be some obstruction in the suction hose. Make sure the suction tube is not clogged or bent sharply. If the suction tube is clear, shut off the flame. Close the tank valve. Disconnect the leak detector from the handle or adaptor. Check for dirt in the filter screw or mixer disc. See Fig. 1-39. Use a 1/8 in. socket key (Allen wrench) to remove or replace the filter screw. This screw retains the mixer disc.

**Detecting Leaks**

To explore the leaks, move the end of the suction hose around all points where there might be leaks. Be careful not to kink the suction hose.

Watch for color changes in the flame as you move the end of the suction hose:
- With the model that has a large opening in the flame shield (wings on each side), a small leak will change the color of the outer flame to a yellow or an orange-yellow hue. As the concentration of halide gas increases, the yellow will disappear. The lower part of the flame will become a bright, light blue. The top of the flame will become a vivid purplish blue.
- With the model that has no wings alongside the flame shield opening, small concentrations of halide gas will change the color. A bright blue-green outer flame indicates a leak. As the concentration of the halide gas increases, the lower part of the flame will lose its greenish tinge. The upper portion will become a vivid purplish blue.
- Watch for color intensity changes. The location of small color leaks can be pinpointed rapidly. Color in the flame will disappear almost instantly after the intake end of the hose has passed the point of leakage. With larger leaks, you will have to judge the point of leakage. Note the color change from yellow to purple-blue or blue-green to blue-purple, depending on the model used.

**Maintenance**

With intensive usage, an oxide scale may form on the surface of the reaction plate. Thus, sensitivity is reduced. Usually this scale can be easily broken away from the late surface. If you suspect a loss in sensitivity,
Ammeter

The ammeter is used to measure current. It can measure the amount of current flowing in a circuit. It may use one of a number of different basic meter movements to accomplish this. The most frequently used of the basic meter movements is the D’Arsonval type. See Fig. 1-40. It uses a permanent magnet and an electromagnet to determine circuit current. The permanent magnet is used as a standard basic source of magnetism. As the current flows through the coil of wire, it creates a magnetic field around it. This magnetic field is strong or weak, depending upon the amount of current flowing through it. The stronger the magnetic field created by the moving coil, the more it is repelled by the permanent magnet. This repelling motion is calibrated to read amperes, milliamperes (0.001 A), or microamperes (0.000001 A).

The D’Arsonval meter movement may also be used on AC when a diode is placed in series with the moving coil winding. The diode changes the AC to DC and the meter works as on DC. See Fig. 1-41. The dial or face of the instrument is calibrated to indicate the AC readings.

There are other types of AC ammeters. They are not always as accurate as the D’Arsonval, but they are effective. In some moving magnet meters, the coil

---

**ELECTRICAL INSTRUMENTS**

Several electrical instruments are used by the air-conditioning serviceperson to see if the equipment is working properly. Studies show that the most trouble calls on heating and cooling equipment are electrical in nature.

The most frequently measured quantities are volts, amperes, and ohms. In some cases, wattage is measured to check for shorts and other malfunctions. A wattage meter is available. However, it must be used to measure volt-amperes (VA) instead of watts. To measure watts, it is necessary to use DC only or convert the VA to watts by using the power factor. The power factor times the volt-amperes produces the actual power consumed in watts. Since most cooling equipment use AC, it is necessary to convert to watts by this method.

A number of factors can be checked with electrical instruments. For example, electrical instruments can be used to check the flow rate from a centrifugal water pump, the condition of a capacitor, or the character of a start or run winding of an electric motor.

---

**Fig. 1-39** Position of filter screw and mixer disc on Prest-O-Lite halide leak detector (A) Standard model. (B) Supersensitive model.
is stationary and the magnet moves. Although rugged, this type is not as accurate as the D’Arsonval type meter.

The moving vane meter is useful in measuring current when AC is used. See Fig. 1-42.

The clamp-on ammeter has already been discussed. It has some limitations. However, it does have one advantage in that it can be used without having to break the line to insert it. Most ammeters must be connected in series with the consuming device. That means one line has to be broken or disconnected to insert the meter into the circuit.

The ampere reading can be used to determine if the unit is drawing too much current or insufficient current. The correct current amount is usually stamped on the nameplate of the motor or the compressor.

Starting and running amperes may be checked to see if the motor is operating with too much load or it is shorted. The flow rate of some pumps can be determined by reading the current the motor pulls. The load on the entire line can be checked by inserting the ammeter in the line. This is done by taking out the fuse and completing the circuit with the meter. Be careful.

If the ammeter has more than one range, it is best to start on the highest range and work down. The reading should be in or near the center of the meter scale for a more accurate reading. Make sure you have some idea what the current in the circuit should be before inserting the meter. Thus, the correct range—or, in some instances, the correct meter—can be selected.
Voltmeter

The voltmeter is used to measure voltage. Voltage is the electrical pressure needed to cause current to flow. The voltmeter is used across the line or across a motor or whatever is being used as a consuming device.

Voltmeters are nothing more than ammeters that are calibrated to read volts. There is, however, an important difference. The voltmeter has a very high internal resistance. That means very small amounts of current flow through its coil. See Fig. 1-43. This high resistance is produced by multipliers. Each range on the voltmeter has a different resistor to increase the resistance so the line current will not be diverted through it. See Fig. 1-44. The voltmeter is placed across the line, whereas the ammeter is placed in series. You do not have to break the line to use the voltmeter. The voltmeter has two leads. If you are measuring DC, you have to observe polarity. The red lead is the positive (+)
and the black lead is the negative (−). However, when AC is used, it does not matter which lead is placed on which terminal. Using a D’Arsonval meter movement, voltmeters can be made with the proper diode to change AC to DC. Voltmeters can be made with a stationary coil and a moving magnet. Others types of voltmeters are available. They use various means of registering voltage.

If the voltage is not known, use the highest scale on the meter. Turn the range switch to appoint where the reading is in the midrange of the meter movement.

Normal line voltage in most locations is 120 V. When the line voltage is lower than normal, it is possible for the equipment to draw excessive current. This will cause overheating and eventual failure and/or burnout. The correct voltage is needed for the equipment to operate according to its designed specifications. The voltage range is usually stamped on the nameplate of the device. Some will state 208 V. This voltage is obtained from a three-phase connection. Most home or residential voltage is supplied at 120 V or 230 V. The range is 220 to 240 V for normal residential service. The size of the wire used to connect the equipment to the line is important. If the wire is too small, voltage will drop. There will be low voltage at the consuming device. For this reason a certified electrician with knowledge of the NEC should wire a new installation.

**Ohmmeter**

The ohmmeter measures resistance. The basic unit of resistance is the ohm (Ω). Every device has resistance. That is why it is necessary to know the proper resistance before trying to troubleshoot a device by using an ohmmeter. The ohmmeter has its own power supply. See Fig. 1-45. Do not use an ohmmeter on a line that is energized or connected to a power source of any voltage.

An ohmmeter can read the resistance of the windings of a motor. If the correct reading has been given by the manufacturer, it is then possible to see if the reading has changed. If the reading is much lower, it may indicate a shorted winding. If the reading is infinite (∞), it may mean there is a loose connection or an open circuit.

Ohmmeters have ranges. Figure 1-46 shows a meter scale. The $R \times 1$ range means the scale is read as is. If the $R \times 10$ range is used, it means that the scale reading must be multiplied by 10. If the $R \times 1000$ range is selected, then the scale reading must be multiplied by 1000. If the meter has a $R \times 1$ meg range, the scale reading must be multiplied by one million. A meg is one million.

**Multimeter**

The multimeter is a combination of meters. See Fig. 1-47. It may have a voltmeter, an ammeter, and an ohmmeter.
in the same case. This is the usual arrangement for fieldwork. This way it is possible to have all three meters in one portable combination. It should be checked for each of the functions.

The snap-around meter uses its scale for a number of applications. It can be read current by snapping around the current carrying wire. If the leads are used, it can be used as a voltmeter or an ohmmeter. Remember that the power must be off to use the ohmmeter. This meter is mounted in its own case. It should be protected from shock and vibration just as any other sensitive instrument.

**Wattmeter**

The wattmeter is used to measure watts. However, when used on an AC line, it measures volt-amperes. If watts are to be measured, the reading must be converted to watts mathematically. Multiply the reading on the wattmeter by the power factor (usually available on the nameplate) to obtain the reading in watts.

Wattmeters use the current and the voltage connections as with individual meters. See Fig. 1-48. One coil is heavy wire and is connected in series. It measures the current. The other connection is made in the same way as with the voltmeter and connected across the line. This coil is made of many turns of fine wire. It measures the voltage. By the action of the two magnetic fields, the current is multiplied by the voltage. Wattage is read on the meter scale.

The volt-ampere is the unit used to measure volts time amperes in an AC circuit. If a device has inductance (as in a motor) or capacitance (some motors have run-capacitors), the true wattage is not given on a wattmeter. The reading is in volt-amperes instead of watts. It is converted to watts by multiplying the reading by the power factor. A wattmeter reads watts only when it is connected to a DC circuit or to an AC circuit with resistance only.

The power factor is the ratio of true power to apparent power. Apparent power is what is read on a wattmeter on an AC line. True power is the wattage reading of DC. The two can be used to find the power factor. The power factor is the cosine of the phase angle. The power factor can be found by using a mathematical computation or a very delicate meter designed for the purpose. However, the power factor of equipment using alternating current is usually stamped on the nameplate of the compressor, the motor, or the unit itself.

Wattmeters are also used to test capacitors. Some companies provide charts to convert wattage ratings to microfarad ratings. The wattmeter can test the actual connection of the capacitor. The ohmmeter tells if the capacitor is good or bad. However, it is hard to indicate how a capacitor will function in a circuit with the...
voltage applied. This is why testing with the wattmeter is preferred.

**OTHER INSTRUMENTS**

Many types of meters and gages are available to test almost any quantity or condition. For example:

- Air–filter efficiency gages
- Air-measurement gages
- Humidity-measuring devices
- Moisture analyzers
- British thermal unit (Btu) meters

Vibration and sound meters and recorders are also available.

**Air–Filter Efficiency Gages**

Air measurements are taken in an air-distribution system. They often reveal the existence and location of unintentionally closed or open dampers and obstructions. Leaks in the ductwork and sharp bends are located this way.

Air measurements frequently show the existence of a blocked filter. Dirty and blocked filters can upset the balance of either a heating or cooling system. This is important whether it is in the home or in a large building.

Certain indicators and gages can be mounted in air plenums. They can be used to show that the filter has reached a point where it is restricting the airflow. An air plenum is a large space above the furnace heating or cooling unit.

**Air-Measurement Instruments**

The volume and velocity of air are important measurements in the temperature control industries. Proper amounts of air are indispensable to the best functioning of refrigeration cycles, regardless of the size of the system. Air-conditioning units and systems also rely upon volume and velocity for proper distribution of conditioned air.

Only a small number of contractors are equipped to measure volume and velocity correctly. The companies that are doing the job properly are in great demand. Professional handling of air volume and velocity ensures the efficient use of equipment. Large buildings are very much in need of the skills of air-balancing teams.

Some people attempt to obtain proper airflow by measuring air temperature. They adjust dampers and blowers speeds. However, they usually fail in their attempts to balance the airflow properly.

There are instruments available to measure air velocity and volume. Such instruments can accurately
measure the low pressures and differentials involved in air distribution.

Draft gages do measure pressure. However, their specific application to air control makes it more appropriate to discuss them here, rather than under pressure gages. They measure pressure in inches of water. They come in several styles. The most familiar is the slanted type. It may be used either in the field or in the shop.

Meter type draft gages are better for fieldwork. They can be carried easily. They can sample air at various locations, with the meter box in one location.

Besides air pressure, it is frequently necessary to measure air volume, which is measured in cubic feet per minute or cfm. Air velocity is measured in feet per minute or fpm. The measure of airflow is still somewhat difficult. However, newer instruments are making accurate measurements possible.

**Humidity-Measurement Instruments**

Many hygroscopic (moisture absorbing) materials can be used as relative-humidity sensors. Such materials absorb or lose moisture until a balance is reached with the surrounding air. A change in material moisture content causes a dimensional change, and this change can be used as an input signal to a controller. Commonly used materials include:

- Human hair
- Wood
- Biwood combinations similar in action to a bimetallic temperature sensor
- Organic films
- Some fabrics, especially certain synthetic fabrics

All these have the drawbacks of slow response and large hysteresis effects. Accuracy also tends to be questionable unless they are frequently calibrated. Field calibration of humidity sensors is difficult.

Humidity is read in rh or relative humidity. To obtain the rh, it is necessary to use two thermometers. One thermometer is a dry bulb, the other is a wet bulb. The device used to measure rh is the sling psychrometer. It has two glass-stem thermometers. The wet bulb thermometer is moistened by a wick attached to the bulb. As the dual thermometers are whirled, air passes over them. The dry and wet bulb temperatures are recorded. Relative humidity is determined by:

- Graphs
- Slide rules
- Similar devices

Thin-film sensors are now available, which use an absorbent deposited on a silicon substrate such that the resistance or capacitance varies with relative humidity. They are quite accurate in the range of ±3 to 5 percent. They also have low maintenance requirements.

**Stationary Psychrometers**  Stationary psychrometers take the same measurements as sling psychrometers. They do not move. However, they use a blower or fan to move the air over the thermometer bulbs.

For approximate rh readings, there are metered devices. They are used on desks and walls. They are not accurate enough to be used in engineering work.

Humidistats, which are humidity controls, are used to control humidifiers. They operate the same way as thermometers in closing contacts to complete a circuit. They do not use the same sensing element, however.

**Moisture Analyzers**  It is sometimes necessary to know the percentage of water in a refrigerant. The water vapor or moisture is measured in parts per million. The necessary measuring instrument is still used primarily in the laboratory. Instruments for measuring humidity are not used here.

**Btu Meters**  The Btu is used to indicate the amount of heat present. Meters are especially designed to indicate the Btu in a chilled water line, a hot water line, or a natural gas line. Specially designed, they are used by skilled laboratory personnel at present.

**Vibration and Sound Meters**  More cities are now prohibiting conditioning units that make too much noise. In most cases, vibration is the main problem. However, it is not an easy task to locate the source of vibration. However, special meters have been designed to aid in the search for vibration noise.

Portable noise meters are available. The dB, or decibel, is the unit for the measurement of sound. There are a couple of bands on the noise meters. The dB-A scale corresponds roughly to the human hearing range. Other scales are available for special applications.

More emphasis is now being placed on noise levels in factories, offices, and schools. The *Occupational Safety and Hazards Act* (OSHA) lays down strict guidelines regarding noise levels. There are penalties for noncompliance. Thus, it will be necessary for all new and previously installed units to be checked for noise.

High-velocity air systems—are used in large buildings—are engineered to reduce noise to levels set by the OSHA. For example, there are chambers to lower the
noise in the ducts. Air engineers are constantly working on high-velocity systems to try to solve some of the problems associated with them.

**SERVICE TOOLS**

Service personnel use some special devices to help them with repair jobs in the field. One of them is the chaser kit. See Fig. 1-49. It is used for cleaning partially plugged capillary tubes. The unit includes 10 spools of lead alloy wire. These wires can be used as chasers for the 10 most popular sizes of capillary tubes. In addition to the wire, a cap tube gage, a set of sizing tools, and a combination file/reamer are included in the metal case. This kit is used in conjunction with the Cap-Check. The Cap-Check is a portable, self-contained hydraulic power unit with auxiliary equipment especially adapted to cleansing refrigeration capillary tubes. See Fig. 1-50. A small plug of wire from the chaser kit is inserted into the capillary tube. The wire is a few thousandths of an inch smaller than the internal diameter of the capillary tube. This wire is pushed like a piston through the capillary tube with hydraulic pressure from the Cap-Check. A 0 to 5000 psi gage shows pressure buildup if the capillary tube is restricted. It also shows when the chaser has passed through the tube. A trigger-operated gage shutoff is provided so the gage will not be damaged if pressure greater than 5000 psi is desired.

When the piston stops against a partial restriction, high-velocity oil is directed around the piston and against the wall, washing the restriction away and allowing the wire to move through the tube. The lead wire eventually ends up in the bottom of the evaporator, where it remains. The capillary tube is then as clean as when it was originally installed.

A 30 in. high-pressure hydraulic hose with a 1/4 in. Society of Automotive Engineers (SAE) male flare outlet connects the cap tube to the Cap-Check for simple handling. An adapter comes with the Cap-Check for simple handling. Another adapter comes with the unit to connect the cap tube directly to the hose outlet without a flared fitting.

![Cap-Check chaser kit](image)

**Fig. 1-49**  Cap-Check chaser kit. This is a means to clean partially plugged capillary tubes. It has 10 spools of lead alloy wire. These wires can be used as a chaser for the 10 most popular sizes of cap tubes. A cap tube gage, set of sizing tools, and a combination file/reamer are included in the kit.

30  Air-Conditioning and Refrigeration Tools and Instruments
Eventually, almost every refrigerant-charging job turns into a vapor-charging job. Unless the compressor is turned on, liquid can be charged into the high side only so long before the system and cylinder pressures become unfavorable. Once that happens, all refrigerant must be taken in the low side in the form of vapor.

Vapor charging is much slower than liquid charging. To create a vapor inside the refrigerant cylinder, the liquid refrigerant must be boiling. Boiling refrigerant absorbs heat. This is the principle on which refrigeration operates.

The boiling refrigerant absorbs heat from the refrigerant surrounding it in the cylinder. The net effect is that the cylinder temperature begins to drop soon after you begin charging with vapor. As the temperature drops, the remaining refrigerant will not vaporize as readily. Charging will be slower.

To speed charging, service personnel add heat to the cylinder by immersing part of it in hot water. The cylinder temperature rises. The boiling refrigerant becomes vigorous and charging returns to a rapid rate. It is not long, though, before all the heat has been taken from the water and more hot water must be added.

The Vizi-Vapr is an example of how a device can remove liquid from a cylinder and apply it to the system in the form of a vapor. See Fig. 1-52. No heat is required. This eliminates the hazards of using a torch and hot water. The change from a liquid to a gas or vapor

The Cap-Gage is a capillary tube gage. It has 10 stainless steel gages to measure the most popular sizes of capillary tubes. See Fig. 1-51.

More up to date tools and test equipment are shown in the Appendices. Go online to find the latest available tools and instruments. One source for tools and test equipment is yellowjacket.com or the Ritchie Engineering Company in Minnesota. Another is Mastercool.com in New Jersey.

Fig. 1-50  Cap-Check is a portable self-contained hydraulic power unit with auxiliary equipment that is especially adapted to cleaning refrigeration capillary tubes. It is hand operated.

Fig. 1-51  The Cap-Gage is a pocketknife-type cap tube gage with 10 stainless steel gages to measure the most popular sizes of cap tubes. (Thermal Engineering)
takes place in the Vizi-Vapr. It restricts the charging line between the cylinder and compressor. This restriction is much like an expansion valve in that it maintains high cylinder pressure behind it to hold the refrigerant as a liquid.

However, it has a large pressure drop across it to start evaporation. Heat required to vaporize refrigerant is taken from the air surrounding the unit, not from the remaining refrigerant. This produces a dense, saturated vapor.

The amount of restriction in the unit is very critical. Too much restriction will slow charging considerably. It also will allow liquid to go through and cause liquid slugging in the compressor. The restriction setting is different for each size system, for different types of refrigerants and even for different ambient temperatures.

VACUUM PUMPS

Use of the vacuum pump may be the single most important development in refrigeration and air-conditioning servicing. The purpose of a vacuum pump is to remove the undesirable materials that create pressure in a refrigeration system. These include:

- Moisture
- Air (oxygen)
- Hydrochloric acid

In addition, there are other materials that will vaporize at low micron range. These, along with a wide variety of solid materials, are pulled into the vacuum pump in the same way a vacuum cleaner sucks up dirt.

Evacuation is being routinely performed on almost every service call on which recharging is required.

NOTE: It is no longer permitted to simply add refrigerant to the system with one end open for evacuation into the atmosphere. This shortcut was a favorite of many service technicians over the years since it was quick and the refrigerant was inexpensive.

Vacuum levels formerly unheard of for field evacuations are being accomplished daily by service persons who are knowledgeable regarding vacuum equipment. These service persons have found through experience that the two-stage pump is much better than the single-stage pump for deep evacuations. See Figs. 1-53 and 1-54. It was devised as a laboratory instrument and with minor alterations; it has been adapted to the refrigeration field. It is the proper tool for vacuum evacuations in the field. The latest in vacuum pumps is shown in Appendix 4.
To understand the advantages of a two-stage pump over a single-stage pump refer to Fig. 1-55. This shows the interior of a two-stage vacuum pump. This is a simplified version of a vacuum stage. It is built on the principle of a Wankel engine.

There is a stationary chamber with an eccentric rotor revolving inside. The sliding vanes pull gases through the intake. They compress them and force them into the atmosphere through the exhaust. The vanes create a vacuum section and a pressure section inside the pump. The seal between the vacuum and the pressure sections is made by the vacuum pump oil. These seals are the critical factor in the depth that a vacuum pump can pull. If the seals leak, the pump will not be able to draw a deep vacuum. Consequently, less gas can be processed. A pump with high leakage across the seal will be able to pull a deep vacuum on a small system, but the leakage will decrease the pumping speed (cfm) in the
deep vacuum region. Long pull-down times will result. There are three oil seals in a single-stage vacuum pump. Each seal must hold against a high pressure on one side and a deep vacuum on the other side. This places a great deal of strain on the oil seal. A two-stage vacuum pump cuts the pressure strain on the oil seal in half. Such a pump uses two chambers instead of one to evacuate a system. The first chamber is called the deep vacuum chamber. It pulls in the vacuum gases from the deep vacuum and exhausts them into the second chamber at a moderate vacuum. The second chamber, or stage, brings in these gases at a moderate vacuum and exhausts them into the atmosphere. By doing this, the work of a single chamber is split between two chambers. This, in turn, cuts in half the strain on each oil seal, which reduces the leakage up to 90 percent.

A two-stage vacuum pump is more effective than a single-stage vacuum pump. For example, a single-stage vacuum pump rated for 1.5 cfm capacity will take one and one-half hours to evacuate one drop of water. A two-stage vacuum pump with the same rating will evacuate the drop in 12 min.

For evacuation of a 5-ton system saturated with moisture, a minimum of 15 h evacuation time is required in using a single-stage vacuum pump. A two-stage vacuum pump with the same cfm rating could do the job in as little as 2 h.

Another advantage of the two-stage pump is reliability. As you can see, if the oil seal is to be effective, the tolerances in these vacuum pumps must be very close between rotor and stator. If the tolerances are not correct, the oil seal will not be effective. Slippage of tolerance due to wear is the major cause of vacuum pump failure. With a single-stage pump, when the tolerance is in the stage slips, the pump loses effectiveness. With a two-stage pump, if one stage loses tolerance, the other one will still pull the vacuum of a single-stage pump.

Larger cfm, two-stage vacuum pumps are preferred to the single-stage vacuum pumps. The cost difference between the two is not great. In addition, the time saved by using the two-stage pump is evident on the first evacuation.

**Vacuum Pump Maintenance**

The purpose of vacuum pump oil is to lubricate the pump and act as a seal. To perform this function the oil must have:

- A low vapor pressure that does not materially increase up to 125°F (51.7°C)
- A viscosity sufficiently low for use at 60°F (15.6°C) yet constant up to 125°F (51.7°C)

These requirements are easily met by using a low vapor pressure, paraffin-based oil having a viscosity of approximately 300 SSU (shearing stress units) at 100°F (37.8°C) and a viscosity index in the range of 95 to 100. This type of uninhibited oil is readily obtainable. It is the material provided by virtually all sellers of vacuum pump oil to the refrigeration trade.

**Vacuum Pump Oil Problems**

The oils used in vacuum pumps are designed to lubricate and seal. Many of the oils available for other jobs are not designed to clean as they lubricate. Neither are they designed to keep in suspension the solids freed by the cleaning action of the oil. In addition, the oil is not usually heavily inhibited against the action of oxygen. Therefore, the vacuum pump must be run with flushing oil periodically to clean it. Otherwise, its efficiency will be reduced. The use of flushing oils is recommended by pump manufacturers.

If hydrochloric acid has been pulled into the pump, water, solids, and oil will bond together to form sludge or slime that may be acidic. The oil also may deteriorate due to oxidation (action on the oil by oxygen in air pulled through the pump). This results in a pump that will not pull a proper vacuum, may wear excessively, seriously corrode, or rust internally.

**Operating Instructions**

Use vacuum-pump oil in the pump when new. After 5 to 10 h of running time, change the oil. Make sure all of the original oil is removed from the pump. Thereafter, change the oil after every 30 h of operation when the oil becomes dark due to suspended solids drawn into
the pump. Such maintenance will ensure peak efficiency in the pump operation.

If the pump has been operated for a considerable time on regular pump oil, drain the oil and replace with dual-purpose vacuum-pump oil. Drain the oil and replace with dual purpose after 10 h of operation. The oil will probably be quite dark due to sludge removed from the pump. Operator the second charge of oil for 10 h and drain again. The second charge of oil may still be dark. However, it will probably be lighter in color than the oil drained after the first 10 h.

Change the oil at 30-h intervals. After that, change the oil before such intervals if it becomes dark due to suspended solids pulled into the pump. Be sure to change the oil every 30 h thereafter to keep the vacuum pump in peak condition.

**Evacuating a System**

How long should it take? Some techniques of evacuation will clean refrigeration and air-conditioning system to a degree never reached before. Properly used, a good vacuum pump will eliminate 99.99 percent of the air and virtually all of the moisture in a system. There is no firm answer regarding the time it will take a pump to accomplish this level of cleanliness. The time required for evacuation depends on many things. Some factors that must be considered are:

- The size of the vacuum pump
- The type of vacuum pump—single or two-stage
- The size of the hose connections
- The size of the system
- The contamination in the system
- The application for the system

Evacuations sometimes take fifteen minutes. Then, again, they may take weeks. The only way to know when evacuation is complete is to take micron vacuum readings, using a good electronic vacuum gage. A number of electronic meters are available. See Figs. 1-56 and 1-57.

Evacuating down to 29 in. eliminates 97 percent of all air. Moisture removal, however, does not begin until a vacuum below 29 in. is reached. This is the micron level of vacuum. It can be measured only with an electronic vacuum gage. Dehydration of system does not certainly begin until the vacuum gage reads below 5000 microns. If the system will not pump down to this level, something is wrong. There may be a leak in the vacuum connections. The vacuum-pump oil may be contaminated. There may be a leak in the system. Vacuum gage readings between 500 and 1000 microns assure that dehydration is proceeding. When all moisture is removed, the micron gage will pull down below 1000 microns.

Pulling a system down below 1000 microns is not a perfect test for cleanliness. If the vacuum pump is too large for the system, it may pull down this level before all of the moisture is removed. Another test is preferred. Once the system is pulled down below 1000 microns it will not go any further. The system should be valved off from the vacuum pump and the pump turned off. If the vacuum in the system does not rise over 2000 microns in the next 5 min, evacuation has been completed. If it goes over this level, either the moisture is not completely removed or the system has a slight leak. To find which, reevacuate the system to its lowest level. Valve it off again and shut off the vacuum pump. If the vacuum leaks back to the same level as before, there is a leak in the system. If, the rise is much slower than before, small amounts of moisture are probably left in the system. Reevacuate until the vacuum will hold.

**CHARGING CYLINDER**

The charging cylinder lets you charge with heat to speed up the charging process. This unit, with its heater assembly, allows up to 50 W of heat to be used in charging. Refrigerant is removed rapidly from the cylinder as liquid, but injected into the system as gas with the Vizi-Vapr. It requires no heat.
during the charging process. The Extracta-Charge device allows the serviceperson to carry small amounts of refrigerant to the job. The refrigerant can be bought in large drums and stored at the shop. The Extracta-Charge comes in a rugged, steel carrying case to protect it from tough use. It provides a method for draining refrigerant even from capillary tube, sealed systems.

It is now mandatory to capture the escaping refrigerant. The Extracta-Charge is the instrument to use. When systems are overcharged, the excess can be transported back to the drum. The amount removed can be measured also. A leak found after the charging operation usually means the loss of the full charge. Using this device, the serviceperson can extract the charge and save it for use after the leak has been found and repaired.

**CHARGING OIL**

In charging a compressor with oil, there is danger of drawing air and moisture into the refrigeration system. Use of the pump shown in Fig. 1-58 eliminates this danger. This pump reduces charging time by over 70 percent without pumping down the compressor. The pump fits the can with a cap seal, so the pump need not be removed until the can is empty. It is a piston-type high-pressure pump designed to operate at pressures up to 250 psi. It pumps one quart in 20 full strokes of the piston. The pump can be connected to the compressor by a refrigerant charging line or copper tubing from a 1/2 in. male flare fitting.
CHANGING OIL
Whenever it is impossible to drain oil in the conventional manner, it becomes necessary to hook up a pump. Removing oil from refrigeration compressors before dehydrating with a vacuum is a necessity. The pump shown in Fig. 1-59 has the ability to remove one quart of oil with about 10 strokes. It is designed for use in pumping oil from refrigeration compressors, marine engines, and other equipment.

MOBILE CHARGING STATIONS
Mobile charging stations can be easily loaded into a pickup truck, van, or station wagon. They take little space. See Fig. 1-60. Stations come complete with manifold gage set, charging cylinder, instrument and tool sack, and vacuum pump. The refrigerant tank can also be mounted on the mobile charging station.

TUBING
Several types of tubing are used in plumbing, refrigeration, and air-conditioning work. Air conditioning and refrigeration, however, use special tubing types. Copper, aluminum, and stainless steel are used for tubing materials. They ensure that refrigerants do not react with the tubing. Each type of tubing has a special application. Most of the tubing used in refrigeration and air conditioning is made of copper. This tubing is especially processed to make sure it is clean and dry inside. It is sealed at the ends to make sure the cleanliness is maintained.

- Stainless steel tubing is used with R-717 or ammonia refrigerant.
- Brass or copper tubing should not be used in ammonia refrigerant systems.
- Aluminum tubing is used in condensers in air-conditioning systems for the home and automobile.

This calls for a special type of treatment for soldering or welding. Copper tubing is the type most often used in refrigeration systems. There are two types of copper tubing—hard-drawn and soft copper tubing. Each has a particular use in refrigeration.

Soft Copper Tubing
Some commercial refrigeration systems use soft copper tubing. However, such tubing is most commonly found in domestic systems. Soft copper is annealed. Annealing is the process whereby the copper is heated to a blue surface color and allowed to cool gradually to room temperature. If copper is hammered or bent repeatedly, it will become hard. Hard copper tubing is subject to cracks and breaking.
Soft copper comes in rolls and is usually under $\frac{1}{2}$ in. in outside diameter (OD). Small-diameter copper tubing is made for capillary use. It is soft drawn and flexible. It comes in random lengths of 90 to 140 ft. Table 1-1 gives the available inside and outside diameters. This type of tubing usually fits in a $\frac{1}{4}$ in. (OD) solder fitting that takes a $\frac{3}{8}$ in. (OD) diameter tubing.

<table>
<thead>
<tr>
<th>Inside Diameter (ID), in.</th>
<th>Outside Diameter (OD), in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.026</td>
<td>.072</td>
</tr>
<tr>
<td>.31</td>
<td>.083</td>
</tr>
<tr>
<td>.036</td>
<td>.087</td>
</tr>
<tr>
<td>.044</td>
<td>.109</td>
</tr>
<tr>
<td>.050</td>
<td>.114</td>
</tr>
<tr>
<td>.055</td>
<td>.125</td>
</tr>
<tr>
<td>.064</td>
<td>.125</td>
</tr>
<tr>
<td>.070</td>
<td>.125</td>
</tr>
<tr>
<td>.080</td>
<td>.145</td>
</tr>
<tr>
<td>.085</td>
<td>.145</td>
</tr>
</tbody>
</table>

*Reducing bushing fits in $\frac{3}{8}$ in. OD solder fitting and takes $\frac{5}{8}$ in. OD tubing.

There are three types of copper tubing—types K, L, and M.

- Type-K tubing is heavy duty. It is used for refrigeration, general plumbing, and heating. It can also be used for underground applications.
- Type-L tubing is used for interior plumbing and heating. Type-M tubing is used for light duty waste vents, water, and drainage purposes.
- Type-K soft copper tubing that comes in 60-ft rolls is available in outside diameters of $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, and $1\frac{1}{8}$ in. It is used for underground water lines. Wall thickness and weight per foot are the same as for hard copper tubing.

Copper tubing used for air-conditioning and refrigeration purposes is marked “ACR.” It is deoxidized and dehydrated to ensure that there is no moisture in it. In most cases, the copper tubing is capped after it is cleaned and filled with nitrogen. Nitrogen keeps it dry and helps prevent oxides from forming inside when it is heated during soldering.

Refrigeration dehydrated and sealed soft copper tubing must meet standard sizes for wall thickness and outside diameter. These sizes are shown in Table 1-2.

Hard and soft copper tubings are available in two wall thicknesses—K and L. The L thickness is used most frequently in air-conditioning and refrigeration systems.

### Hard-Drawn Copper Tubing

Hard-drawn copper tubing is most frequently used in refrigeration and air-conditioning systems. Since it is hard and stiff, it does not need the supports required by soft copper tubing. This type of tubing is not easily bent. In fact, it should not be bent for refrigeration work. That is why there are several tubing fittings available for this type of tubing.

Hard-drawn tubing comes in 10 or 20 ft lengths. See Table 1-3. Remember, there is a difference between hard copper sizes and nominal pipe sizes. Table 1-4 shows the differences. Nominal sizes are used in water lines, home plumbing, and drains. They are never used in refrigeration systems. Keep in mind that Type K is

<table>
<thead>
<tr>
<th>Table 1-2</th>
<th>Dehydrated and Sealed Copper Tubing Outside Diameters, Wall Thicknesses, and Weights*</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-Foot Coils</td>
<td></td>
</tr>
<tr>
<td>Outside Diameter (in.)</td>
<td>Wall Thickness (in.)</td>
</tr>
<tr>
<td>$\frac{5}{32}$</td>
<td>.030</td>
</tr>
<tr>
<td>$\frac{3}{16}$</td>
<td>.030</td>
</tr>
<tr>
<td>$\frac{1}{4}$</td>
<td>.030</td>
</tr>
<tr>
<td>$\frac{5}{32}$</td>
<td>.032</td>
</tr>
<tr>
<td>$\frac{3}{16}$</td>
<td>.032</td>
</tr>
<tr>
<td>$\frac{1}{8}$</td>
<td>.032</td>
</tr>
<tr>
<td>$\frac{5}{32}$</td>
<td>.035</td>
</tr>
<tr>
<td>$\frac{3}{16}$</td>
<td>.035</td>
</tr>
<tr>
<td>$\frac{1}{8}$</td>
<td>.045</td>
</tr>
<tr>
<td>$\frac{1}{8}$</td>
<td>.050</td>
</tr>
<tr>
<td>$\frac{3}{16}$</td>
<td>.055</td>
</tr>
</tbody>
</table>

*The standard soft dehydrated copper tubing is made in the wall thickness recommended by the Copper and Brass Research Association to the National Bureau of Standards. Each size has ample strength for its capacity.
To provide further dryness and cleanliness, nitrogen, an inert gas, is used to fill the tube. It materially reduces the oxide formation during brazing. The remaining nitrogen limits excess oxides during succeeding brazing operations. Where tubing will be exposed inside food compartments, tinned copper is recommended.

To uncoil the tube without kinks, hold one free end against the floor or on a bench. Uncoil along the floor or bench to the desired length. The tube may be cut to length with a hacksaw or a tube cutter. In either case, deburr the end before flaring. Bending is accomplished by use of an internal or external bending spring. Lever-type bending tools may also be used. These tools will be shown and explained later.

The hacksaw should have a 32-tooth blade. The blade should have a wave set. No filings or chips can be allowed to enter the tubing. Hold the tubing so that when it is cut the scraps will fall out of the usable end.

To uncoil the tube without kinks, hold one free end against the floor or on a bench. Uncoil along the floor or bench to the desired length. The tube may be cut to length with a hacksaw or a tube cutter. In either case, deburr the end before flaring. Bending is accomplished by use of an internal or external bending spring. Lever-type bending tools may also be used. These tools will be shown and explained later.

The hacksaw should have a 32-tooth blade. The blade should have a wave set. No filings or chips can be allowed to enter the tubing. Hold the tubing so that when it is cut the scraps will fall out of the usable end.

Figure 1-61 shows some of the tubing cutters available. The tubing cutter is moved over the spot to be cut. The cutting wheel is adjusted so it touches the

Table 1-3  Outside Diameter, Wall Thickness, and Weight per Foot of Hard Copper Refrigeration Tubing

<table>
<thead>
<tr>
<th>Outside Diameter (in.)</th>
<th>Wall Thickness</th>
<th>Weight Per Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>0.418</td>
<td>0.641</td>
</tr>
<tr>
<td>7/8</td>
<td>0.049</td>
<td>0.344</td>
</tr>
<tr>
<td>5/8</td>
<td>0.049</td>
<td>0.418</td>
</tr>
<tr>
<td>3/8</td>
<td>0.035</td>
<td>0.145</td>
</tr>
<tr>
<td>5/16</td>
<td>0.028</td>
<td>0.328</td>
</tr>
<tr>
<td>7/16</td>
<td>0.030</td>
<td>0.126</td>
</tr>
<tr>
<td>5/16</td>
<td>0.025</td>
<td>0.145</td>
</tr>
<tr>
<td>7/16</td>
<td>0.028</td>
<td>0.204</td>
</tr>
<tr>
<td>3/16</td>
<td>0.032</td>
<td>0.485</td>
</tr>
<tr>
<td>1/2</td>
<td>0.035</td>
<td>0.485</td>
</tr>
<tr>
<td>1/2</td>
<td>0.042</td>
<td>0.682</td>
</tr>
<tr>
<td>3/8</td>
<td>0.049</td>
<td>0.940</td>
</tr>
</tbody>
</table>

Table 1-4  Comparison of Outside Diameter and Nominal Pipe Size

<table>
<thead>
<tr>
<th>Outside Diameter (in.)</th>
<th>Nominal Pipe Size (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>1/4</td>
</tr>
<tr>
<td>1/2</td>
<td>3/8</td>
</tr>
<tr>
<td>5/8</td>
<td>1/2</td>
</tr>
<tr>
<td>3/8</td>
<td>5/8</td>
</tr>
<tr>
<td>1/2</td>
<td>7/8</td>
</tr>
<tr>
<td>1/2</td>
<td>11/8</td>
</tr>
<tr>
<td>1/2</td>
<td>13/8</td>
</tr>
<tr>
<td>1/2</td>
<td>15/8</td>
</tr>
<tr>
<td>1/2</td>
<td>17/8</td>
</tr>
<tr>
<td>1/2</td>
<td>19/8</td>
</tr>
<tr>
<td>1/2</td>
<td>21/8</td>
</tr>
<tr>
<td>1/2</td>
<td>23/8</td>
</tr>
<tr>
<td>1/2</td>
<td>25/8</td>
</tr>
<tr>
<td>1/2</td>
<td>31/8</td>
</tr>
<tr>
<td>1/2</td>
<td>41/8</td>
</tr>
</tbody>
</table>

Table 1-4  Comparison of Outside Diameter and Nominal Pipe Size

<table>
<thead>
<tr>
<th>Outside Diameter (in.)</th>
<th>Nominal Pipe Size (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>1/4</td>
</tr>
<tr>
<td>1/2</td>
<td>3/8</td>
</tr>
<tr>
<td>5/8</td>
<td>1/2</td>
</tr>
<tr>
<td>3/8</td>
<td>5/8</td>
</tr>
<tr>
<td>1/2</td>
<td>7/8</td>
</tr>
<tr>
<td>1/2</td>
<td>11/8</td>
</tr>
<tr>
<td>1/2</td>
<td>13/8</td>
</tr>
<tr>
<td>1/2</td>
<td>15/8</td>
</tr>
<tr>
<td>1/2</td>
<td>17/8</td>
</tr>
<tr>
<td>1/2</td>
<td>19/8</td>
</tr>
<tr>
<td>1/2</td>
<td>21/8</td>
</tr>
<tr>
<td>1/2</td>
<td>23/8</td>
</tr>
<tr>
<td>1/2</td>
<td>25/8</td>
</tr>
<tr>
<td>1/2</td>
<td>31/8</td>
</tr>
<tr>
<td>1/2</td>
<td>41/8</td>
</tr>
</tbody>
</table>

heavy-wall tubing, Type L is medium-wall tubing, and Type M is thin-wall tubing. The thickness determines the pressure the tubing will safely handle.

Cutting Copper Tubing

Copper tubing can be cut with a copper tube cutter or a hacksaw. ACR tubing is cleaned, degreased, and dried before the end is sealed at the factory. The sealing plugs are reusable.
copper. A slight pressure is applied to the tightening knob on the cutter to penetrate the copper slightly. Then the knob is rotated around the tubing. Once around, it is tightened again to make a deeper cut. Rotate again to make a deeper cut. Do this by degrees so that the tubing is not crushed during the cutting operation.

After the tubing is cut through, it will have a crushed end. The crushed end is prepared for flaring by filing and reaming. See Fig. 1-62. A file and the deburring attachment on the cutting tool can also be used. After the tubing is cut to length, it probably will require flaring or soldering.

**Flaring Copper Tubing**

A flaring tool is used to spread the end of the cut copper tubing outward. Two types of tools are designed for this operation. See Fig. 1-63. The flaring process is shown in Fig. 1-64. Note that the flaring is done by holding the end of the tubing rigid at a point slightly below the protruding part of the tube. This protruding part allows for the stretching of the copper.

A flare is important for a strong, solid, leak-proof joint. The flares shown in Fig. 1-64 are single flares. These are used in most refrigeration systems. The other type of flare is the double flare. Here the metal is doubled over to make a stronger joint. They are used in commercial refrigeration and automobile air conditioners. Figure 1-65 shows how the double flare is made. The tool used is called a block-and-punch.
uses the flare connection on all three ends. The half-union elbow uses the flare at one end and a male pipe thread (MPT) on the other end. A female pipe thread is designated by the abbreviation FPT.

Double flaring is recommended for copper tubing \( \frac{5}{16} \text{ in.} \) and over. Double flares are not easily formed on smaller sizes of tubing.

**Constricting Tubing**

A tubing cutter adapted with a roller wheel is used to constrict a tubing joint. Two tubes are placed so that one is inserted inside the other. They should be within 0.003 in. when inserted. This space is then constricted by a special wheel on the tube cutter. See Fig. 1-68. The one shown is a combination tube cutter and constrictor. The wheel tightens the outside tube around the inside tube. The space between the two is then filled with solder. Of course, proper cleanliness for the solder joint must be observed before attempting to fill the space with solder.

Both pieces of tubing must be hot enough to melt the solder. Flux must be used to prevent oxidation during the heating cycle. Place flux only on the tube to be inserted. No flux should be allowed to penetrate the inside of the tubing. It can clog filters and restrict refrigerant flow.

**Swaging Copper Tubing**

Swaging joins two pieces of copper without a coupling. This makes only one joint, instead of the two that would be formed if a coupling were used. With

---

*Fig. 1-64 Flaring tools. (A) This type of tool calls for the tubing to be inserted into the proper size hole with a small amount of the tube sticking above the flaring block. (B) This type of tool calls for the tubing to stick well above the flaring block. This type is able to maintain the original wall thickness at the base of the flare. The faceted flaring cone smooths out any surface imperfections.*

Adapters can be used with a single-flare tool to produce a double flare. See Fig. 1-66.

Figure 1-67 shows joints that use the flare. The flared tubing fits over the beveled ends. The flare tee

*Fig. 1-65 Double flares formed by the punch-and-block method. (1) Tubing is clamped into the block opening of the proper size. The female punch, Punch A, is inserted into the tubing. (2) Punch A is tapped to bend the tubing inward. (3) The male punch, Punch B, is tapped to bend the tubing inward. (4) The male punch is tapped to create the final double flare.*
fewer joints, there are fewer chances of leaks. Punch-type swaging tools and screw-type swaging tools are used in refrigeration work. The screw-type swaging tool works the same as the flaring tool.

Tubing is swaged so that one piece of tubing is enlarged to the outside diameter of the other tube. The two pieces of soft copper are arranged so that the inserted end of the tubing is inside the enlarged end by the same amount as the diameter of the tubing used. See Fig. 1-69. Once the areas have been properly prepared for soldering, the connection is soldered. Today, most mechanics use fittings, rather than take the time to prepare the swaged end.

**Forming Refrigerant Tubing**

There are two types of bending tools made of springs. One fits inside the tubing. The other fits outside and over the tubing being bent. See Fig. 1-70. Tubing must be bent so that it does not collapse and flatten. To prevent this, it is necessary to place some device over the tubing to make sure that the bending pressure is applied evenly. A tube bending spring may be fitted either inside or outside the copper tube while it is being bent. See Fig. 1-71. Keep in mind that the minimum safe distance for bending small tubing is five times its diameter. On larger tubing, the minimum safe distance is ten times the diameter. This prevents the tubing from flattening or buckling.

Make sure the bending is done slowly and carefully. Make a large radius bend first, then go on to the smaller bends. Do not try to make the whole bend at one time. A number of small bends will equalize the applied pressure and prevent tubing collapse. When using the internal bending spring, make sure part of it
is outside the tubing. This gives you a handle on it when it is time to remove it after the bending. You may have to twist the spring to release it after the bend. By bending it so the spring compresses, it will become smaller in diameter, and pull out easily. The external spring is usually used in bending tubing along the midpoint. It is best to use the internal spring when a bend comes near the end of the tubing or close to a flared end.

The lever-type tube bender is also used for bending copper tubing. See Fig. 1-72. This one-piece open-side bender makes a neat, accurate bend since it is calibrated in degrees. It can be used to make bends up to 180°. A 180° bend is U-shaped. This tool is to be used when working with hard-drawn copper or steel tubing. It can also be used to bend soft copper tubing. The springs are used only for soft copper, since the hard-drawn copper would be difficult to bend by hand. Hard-drawn copper tubing can be bent, if necessary, using tools that electricians use to bend conduit.

### Fitting Copper Tubing by Compression

Making leak-proof and vibration-proof connections can be difficult. A capillary tube connection can be used. See Fig. 1-73. This compression fitting is used with a capillary tube. The tube extends through the nut and into the connector fitting. The nose section is forced tightly against the connector fitting as the nut is tightened. The tip of the nose is squeezed against the tubing.

If you service this type of fitting, you must cut back the tubing at the end and replace the soft nose nut. If the nut is reused, it will probably cause a leaky connection.

### SOLDERING

Much refrigeration work requires soldering. Brass parts, copper tubing, and fittings are soldered. The
cooling unit is also soldered. Thus, the air-conditioning and refrigeration mechanic should be able to solder properly.

Two types of solders are used in refrigeration and air-conditioning work. Soft solder and silver solder are most commonly used for making good joints. Brazing is actually silver soldering. Brazing requires careful preparation of the products prior to heating for brazing or soldering. This preparation must include steps to prevent contaminants such as dirt, chips, flux residue, and oxides from entering and remaining in an installation. A general-purpose solder for cold water lines and hot water lines with temperatures below 250°F (121.1°C) is 50-50. The solder is made of 50 percent tin and 50 percent lead. The 50-50 solder flows at 414°F (212.2°C).

Another low-temperature solder is 95-5. It flows at 465°F (240.5°C). It has a higher resistance to corrosion. It will result in a joint shear strength approximately two and a half times that of a 50-50 joint at 250°F (121.1°C).

A higher temperature solder is No. 122. It is 45 percent silver brazing alloy. This solder flows at 1145°F (618.2°C). It provides a joining material that is suitable for a joint strength greater than the other two solders. It is recommended for use on ACR copper tubing.

Number 50 solder is 50-50 lead and tin. Number 95 solder is 95 percent tin and 5 percent antimony. Silver solder is really brazing rod, instead of solder. The higher temperature requires a torch to melt it.

**Soft Soldering**

Soldering calls for a very clean surface. Sand-cloth is used to clean the copper surfaces. Flux must be added to prevent oxidation of the copper during the heating process. A no-corrode solder is necessary. See Fig. 1-6. Acid-core solder must not be used. The acid in the solder will corrode the copper and cause leaks.

Soldering is nothing more than applying a molten metal to join two pieces of tubing or a tubing end and a fitting. It is important that both pieces of metal being joined are at the flow point of the solder being used. Never use the torch to melt the solder. The torch is used to heat the tubing or fitting until it is hot enough to melt the solder.

The steps in making a good solder joint are shown in Fig. 1-74. Cleanliness is essential. Flux can damage any system. It is very important to keep flux out of the lines being soldered. The use of excessive amounts of solder paste affects the operation of a refrigeration system. This is especially true of R-22 systems. Solder paste will dissolve in the refrigerant at the high liquid line temperature. It is then carried through a drier or strainer and separated out at the colder expansion valve temperature. Generally, R-22 systems will be more seriously affected than those carrying R-12. This is because the solid materials separate out at a higher
Soldering procedures. (1) Cut the tubing to length and remove the burrs. (2) Clean the joint area with sandpaper or sand-cloth. (3) Clean inside the fitting. Use sandpaper, sand-cloth, or wire brush. (4) Apply flux to the inside of the fitting. (5) Apply flux to the outside of the tubing. (6) Assemble the fitting onto the tubing. (7) Obtain proper tip for the torch and light it. Adjust the flame for the soldering being done. (8) Apply heat to the joint. (9) When solder can be melted by the heat of the copper (not the torch), simply apply solder so it flows around the joint. (10) Clean the joint of excess solder and cool it quickly with a damp rag.
temperature. Sound practice would indicate the use of only enough solder paste to secure a good joint. The paste should be applied according to directions specified by the manufacturer.

**Silver Soldering or Brazing**

Silver solder melts at about 1120°F (604.4°C) and flows at 1145°F (618°C). An acetylene torch is needed for the high heat. It is used primarily on hard-drawn copper tubing.

**CAUTION:** Before using silver solder, make sure it does not contain cadmium. Cadmium fumes are very poisonous. Make sure you work in a very well-ventilated room. The fumes should not contact your skin or eyes. Do not breathe the fumes from the cadmium type of silver solder. Most manufacturers will list the contents on the container.

Silver soldering also calls for a clean joint area. Use the same procedures as shown previously for soldering. See Fig. 1-74. Figure 1-75 shows good and poor design characteristics. No flux should enter the system being soldered. Make your plans carefully to prevent any flux entering the tubing being soldered.

Nitrogen or carbon dioxide can be used to fill the refrigeration system during brazing. This will prevent any explosion or the creation of phosgene when the joint has been cleaned with carbon tetrachloride.

In silver soldering, you need a tip that is several sizes larger than the one used for soft soldering. The pieces should be heated sufficiently to have the silver solder adhere to them. Never hold the torch in one place. Keep it moving. Use a slight feather on the inner cone of the flame to make sure you have the proper heat. A large soft flame may be used to make sure the tip does not burn through the fitting or the tubing being soldered.

It is necessary to disassemble sweat-type valves when soldering to the connecting lines. In soldering sweat-type valves where they connect to a line, make sure the torch flame is directed away from the valve. Avoid excessive heat on the valve diaphragm. As an extra precaution, a damp cloth may be wrapped around the diaphragm during the soldering operation. The same is true for soldering thermostatic expansion valves to the distributor.

Either soft or hard solder or silver brazing is acceptable in soldering thermostatic expansion valves. Keep the flame at the fittings and away from the valve body and distributor tube joints. Do not overheat. Always solder the outside diameter (OD) of the distributor, never the inside diameter (ID).
**TESTING FOR LEAKS**

Never use oxygen to test a joint for leaks. Any oil in contact with oxygen under pressure will form an explosive mixture.

Do not use emery cloth to clean a copper joint. Emery cloth contains oil. This may hinder the making of a good soldering joint. Emery cloth is made of silicon carbide, which is a very hard substance. Any grains of this abrasive in the refrigeration mechanism or lines can damage a compressor. Use a brush to help clean the area after sanding.

**CLEANING AND DEGREASING SOLVENTS**

Solvents, including carbon tetrachloride (CCl4), are frequently used in the refrigeration industry for cleaning and degreasing equipment. No solvent is absolutely safe. There are several which may be used with relative safety. Carbon tetrachloride is not one of them. Use of one of the safer solvents will reduce the likelihood of serious illness developing in the course of daily use. Some of these solvents are stabilized methyl chloroform, methylene chloride, trichlorethylene, and perchloroethylene. Some petroleum solvents are available. These are flammable in varying degrees.

Most solvents may be used safely if certain rules are followed.

- Use no more solvent than the job requires. This helps keep solvent vapor concentrations low in the work area.
- Use the solvent in a well-ventilated area and avoid breathing the vapors as much as possible. If the solvents are used in shop degreasing, it is wise to have a ventilated degreasing unit to keep the level of solvent vapors as low as possible.
- Keep the solvents off the skin as much as possible. All solvents are capable of removing the oils and waxes that keep the skin soft and moist. When these oils and waxes are removed, the skin becomes irritated, dry, and cracked. A skin rash may develop more easily.

**CAUTION:** While commonly used solvent, carbon tetrachloride has many virtues as a solvent, it has caused much illness among those who use it. Each year several deaths result from its use. Usually, these occur in the small shop or the home. Most large industries have discontinued its use. It is used only with extreme caution. A measure of its harmful nature is indicated by the fact that it bears a poison label. It should never be placed in a container that is not labeled “poison.” It is for industrial use only.

While occasional deaths result from swallowing carbon tetrachloride, the vast majority of deaths are caused by breathing its vapors. When exposure is very great, the symptoms will be headache, dizziness, nausea, vomiting, and abdominal cramping. The person may lose consciousness. While the person seems to recover from breathing too much of the vapor, a day or two later he or she again becomes ill. Now there is evidence of severe injury to the liver and kidneys. In many cases, this delayed injury may develop after repeated small exposures or after a single exposure not sufficient to cause illness at the time of exposure. The delayed illness is much more common and more severe among those who drink alcoholic beverages. In some episodes where several persons were equally exposed to carbon tetrachloride, the only one who became ill or the one who became most seriously ill was the person who stopped for a drink or two on the way home. When overexposure to carbon tetrachloride results in liver and kidney damage, the patient begins a fight for life without the benefit of an antidote. The only sure protection against such serious illness is not to breathe the vapors or allow contact with the skin.

Human response to carbon tetrachloride is not predictable. A person may occasionally use carbon tetrachloride in the same job in the same way without apparent harm. Then, one day severe illness may result. This unpredictability of response is one factor that makes the use of “carbon tet” so dangerous.

Other solvents will do a good job of cleaning and degreasing. It is much safer to select one of those solvents for regular use rather than to expose yourself to the potential dangers of carbon tetrachloride.

**REVIEW QUESTIONS**

1. What does NEC stand for?
2. What type of solder core is preferred for electrical work?
3. What type of tips must masonry drill bits have?
4. What is a thermocouple?
5. What is a thermistor?
6. What is superheat?
7. What symbol identifies infinite resistance on an ohmmeter?
8. What is a draft gage?
9. What is the difference between a sling psychrometer and a stationary psychrometer?
10. Where are humidistats used?
11. What is a British thermal unit (Btu)?
12. What is a capillary tube?
13. Why is vapor charging slower than liquid charging?
14. What is the purpose of a vacuum pump?
15. What is a micron?
16. What type of tubing is needed with R-717 or ammonia refrigerant?
17. Name the three types of copper tubing and describe each.
18. What does ACR on a piece of copper tubing signify?
19. How do you shape or form copper tubing without collapsing it?
20. What is swaging?
21. At what temperature does silver solder melt?