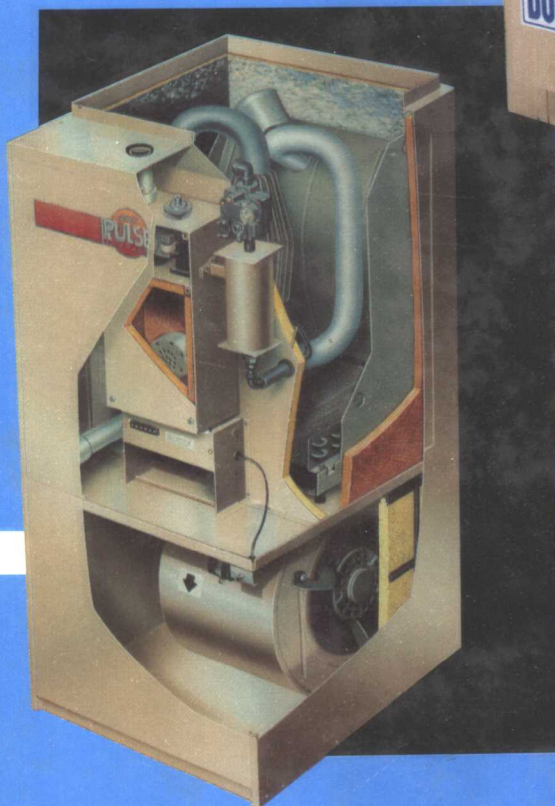
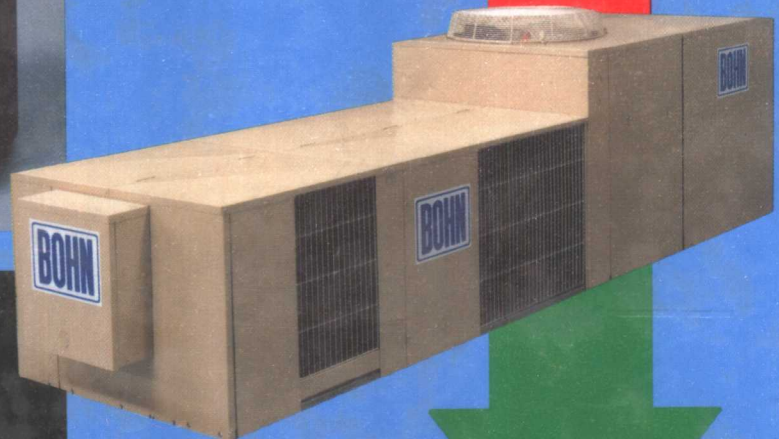
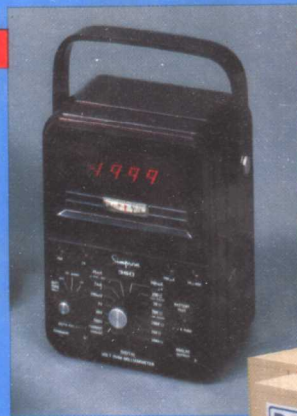


REFRIGERATION & AIR CONDITIONING TECHNOLOGY



REVISED

**WILLIAM C. WHITMAN
WILLIAM M. JOHNSON**

REFRIGERATION AND AIR CONDITIONING TECHNOLOGY

Concepts, Procedures, and Troubleshooting Techniques

**WILLIAM C. WHITMAN
WILLIAM M. JOHNSON**

**Central Piedmont Community College
Charlotte, North Carolina**



delmar publishers inc.

**Revised to Include Three
Units on Domestic Appliances**

COVER PHOTOS:

Upper left-hand photo: *Courtesy of Simpson Electric Company, Elgin, Illinois*

Upper right-hand photo: *Courtesy of Bohn Heat Transfer, Division of Wickes Manufacturing Company, Danville, Illinois*

Lower right-hand photo: *Courtesy of Honeywell, Inc., Golden Valley, Minnesota*

Lower left-hand photo: *Courtesy of Lennox Industries, Inc., Dallas, Texas*

ILLUSTRATOR: Bob Rome

Delmar Staff

Managing Editor: Barbara Christie

Production Editor: Eleanor Isenhardt

Design Coordinator: Susan Mathews

Production Coordinator: Karen Seebald

For information, address Delmar Publishers Inc.,
2 Computer Drive West, Box 15-015,
Albany, New York 12212

COPYRIGHT © 1988

BY DELMAR PUBLISHERS INC.

All rights reserved. Certain portions of this work © 1987.

No part of this work covered by the copyright hereon
may be reproduced or used in any form or by any means—graphic,
electronic, or mechanical, including photocopying, recording, taping, or
information storage and retrieval systems—without written permission
of the publisher.

Printed in the United States of America

Published simultaneously in Canada

by Nelson Canada

A Division of International Thomson Limited

10 9 8 7 6 5 4 3

Library of Congress Cataloging-in-Publication Data

Whitman, William C.

Refrigeration and air conditioning technology : concepts,
procedures, and troubleshooting techniques / William C. Whitman,
William M. Johnson.—Rev. to include three units on domestic appliances.

p. cm.

Includes index.

ISBN 0-8273-3478-8. ISBN 0-8273-2417-0 (instructor's guide)

ISBN 0-8273-2418-9 (student guide)

1. Refrigeration and refrigerating machinery.

2. Air conditioning. I. Johnson, William M. II. Title.

TP492.W6 1988

621.5'6—dc19

88-16136

CIP

PREFACE

Refrigeration and Air Conditioning Technology was written because we felt that a text was needed to better suit the students and instructional staff in the Air Conditioning and Refrigeration Technology program at our institution.

The text is flexible enough to meet the needs of most readers. After completing the first three sections, you may concentrate on courses in refrigeration or air conditioning (heating and/or cooling). If your objective is to complete a whole curriculum, you may proceed until you have finished the sequence scheduled by your school's curriculum.

We have tried to make the text easy to read and to present the material in a practical way, using everyday language and occasionally using terms more commonly used by mechanics and technicians. Our approach to electrical application, for instance, differs from standard treatments—we classify components as “power passing” or “power consuming.”

Objectives are listed at the beginning of each unit. A summary and review questions are provided at the end of each unit. Students should answer the questions while reviewing what they have read; instructors can use the questions to stimulate class discussion and for classroom unit review. The questions are not necessarily designed for testing.

Practical troubleshooting procedures are a main feature of this text. There are practical component and system troubleshooting suggestions and techniques. In many units practical examples of service technician calls are presented in a down-to-earth situational format.

One unit is dedicated to general safety precautions.

This includes general safety procedures and describes tools and equipment that can be used to prevent injury. Specific safety techniques and tips are highlighted throughout the text.

A significant feature of this text is the section on heating. We tried to include heating systems found throughout the country. Obviously some of these heating systems are more appropriate for some geographical areas than others. These heating systems are presented separately by unit so that a unit can easily be skipped if the instructional program does not include it. At the suggestion of several people, we have included a unit on wood heat.

Another section is devoted to all-weather systems and heat pumps. The number of heat pump installations in temperate climates have risen dramatically. Some increase has also occurred in the colder areas.

This text covers some older systems of heating and cooling as well as newer designs since there are thousands of older systems still existing that need servicing.

Refrigeration and Air Conditioning Technology can be used by students as a general reference after completing their program of study. Salespeople, suppliers, contractors, installers, and service technicians can also benefit from the use of this text.

We would like to thank the following reviewers for their help in developing this text. Bill Abernathy, formerly of Orange Coast College; Herschael Blitz, Wayne County Community College; Harvey Castelaz, Milwaukee Area Technical College; Walter Hilmes, Indiana Vocational Technical College; and Henry Puzio, Lincoln Technical Institute.

BRIEF CONTENTS

Preface			
SECTION 1 THEORY OF HEAT	1	SECTION 5 ELECTRIC MOTORS	363
Unit 1 Theory	1	Unit 26 Types of Electric Motors	363
Unit 2 Matter and Energy	13	Unit 27 Application of Motors	380
Unit 3 Refrigeration and Refrigerants	19	Unit 28 Motor Starting	395
		Unit 29 Troubleshooting Electric Motors	405
SECTION 2 SHOP PRACTICES AND TOOLS	41	SECTION 6 AIR CONDITIONING (HEATING AND HUMIDIFICATION)	417
Unit 4 Tools and Equipment	41	Unit 30 Electric Heat	417
Unit 5 Fasteners	55	Unit 31 Gas Heat	431
Unit 6 Tubing and Piping	61	Unit 32 Oil Heat	472
Unit 7 System Evacuation	78	Unit 33 Hydronic Heat	504
Unit 8 System Charging	93	Unit 34 Solar Heat	517
Unit 9 Calibrating Instruments	100	Unit 35 Wood Heat	540
Unit 10 Safety	113	Unit 36 Humidification	555
SECTION 3 BASIC AUTOMATIC CONTROLS	121	SECTION 7 AIR CONDITIONING (COOLING)	563
Unit 11 Basic Electricity and Magnetism	121	Unit 37 Comfort	563
Unit 12 Introduction to Automatic Controls	138	Unit 38 Refrigeration Applied to Air Conditioning	575
Unit 13 System Control Components	148	Unit 39 Air Distribution and Balance	592
Unit 14 Controlling the Temperature of Mass	157	Unit 40 Installation	623
Unit 15 Pressure-Sensing Devices	164	Unit 41 Controls	645
Unit 16 Troubleshooting Basic Controls	173	Unit 42 Typical Operating Conditions	657
Unit 17 Troubleshooting Mechanical and Electromechanical Controls	188	Unit 43 Troubleshooting	670
Unit 18 Electronic and Programmable Controls	193	SECTION 8 ALL-WEATHER SYSTEMS	693
SECTION 4 COMMERCIAL REFRIGERATION	207	Unit 44 Electric, Gas and Oil Heat with Electric Air Conditioning	693
Unit 19 The Compression Cycle, Evaporators	207	Unit 45 Heat Pumps	703
Unit 20 Condensers	222	Appendix I Load Estimation Procedures	744
Unit 21 Compressors	239	Appendix II Domestic Appliances	773
Unit 22 Expansion Devices	258	Appendix III Temperature Conversion Table	879
Unit 23 Special Refrigeration System Components	277	Appendix IV Electrical Symbols Chart	881
Unit 24 Application of Refrigeration Systems	301	Glossary	882
Unit 25 Troubleshooting and Typical Operating Conditions for Commercial Refrigeration	319	Index	894

CONTENTS

Preface

SECTION 1 THEORY OF HEAT

Unit 1 THEORY

1.1 Temperature 1.2 Introduction to Heat 1.3 Conduction 1.4 Convection
1.5 Radiation 1.6 Sensible Heat 1.7 Latent Heat 1.8 Specific Heat 1.9 Sizing
Heating Equipment 1.10 Pressure 1.11 Atmospheric Pressure 1.12 Pressure
Gages Summary Review Questions

Unit 2 MATTER AND ENERGY

2.1 Matter 2.2 Mass 2.3 Density 2.4 Specific Gravity 2.5 Specific Volume
2.6 Energy 2.7 Conservation of Energy 2.8 Energy Contained in Heat 2.9 Energy
in Magnetism 2.10 Purchase of Energy 2.11 Energy Used as Work 2.12 Horsepower
2.13 Electrical Power—The Watt 2.14 The British Thermal Unit Summary
Review Questions

Unit 3 REFRIGERATION AND REFRIGERANTS

3.1 History of Refrigeration 3.2 Refrigeration 3.3 Rating Refrigeration Equipment
3.4 The Refrigeration Process 3.5 Pressure and Temperature Relationship 3.6 Refrigeration
Components 3.7 The Evaporator 3.8 The Compressor 3.9 The Condenser 3.10 The
Refrigerant Metering Device 3.11 Refrigeration System and Components 3.12 Refrigerants
3.13 Refrigerant Must Be Safe 3.14 Refrigerant Must Be Detectable 3.15 The Boiling Point
of the Refrigerant 3.16 Pumping Characteristics 3.17 Refrigerant Chemical Makeup
Summary Review Questions

SECTION 2 SHOP PRACTICES AND TOOLS

Unit 4 TOOLS AND EQUIPMENT

4.1 General Hand Tools 4.2 Specialized Hand Tools 4.3 Specialized Service and
Installation Equipment Summary Review Questions

Unit 5 FASTENERS

5.1 Nails 5.2 Staples and Rivets 5.3 Threaded Fasteners 5.4 Other Fasteners
Summary Review Questions

Unit 6 TUBING AND PIPING

6.1 Purpose of Tubing and Piping 6.2 Types and Sizes of Tubing 6.3 Tubing Insulation
6.4 Line Sets 6.5 Cutting Tubing 6.6 Bending Tubing 6.7 Soldering and Brazing
Processes 6.8 Heat Sources for Soldering and Brazing 6.9 Soldering Techniques
6.10 Brazing Techniques 6.11 Making Flare Joints 6.12 Making a Double-Thickness Flare
6.13 Swaging Techniques 6.14 Steel and Wrought Iron Pipe 6.15 Joining Steel Pipe
6.16 Installing Steel Pipe 6.17 Plastic Pipe Summary Review Questions

Unit 7 SYSTEM EVACUATION

7.1 Purpose of System Evacuation 7.2 Theory Involved with Evacuation 7.3 Measuring
the Vacuum 7.4 The Vacuum Pump 7.5 Deep Vacuum 7.6 Multiple Evacuation
7.7 Leak Detection while in a Vacuum 7.8 Leak Detection—Standing Pressure Test
7.9 Removing Moisture with a Vacuum 7.10 General Evacuation Procedures
7.11 Systems with Schrader Valves 7.12 Gage Manifold Hoses 7.13 System Valves
7.14 Using Dry Nitrogen Summary Review Questions

Unit 8	SYSTEM CHARGING	93
	8.1 Charging a Refrigeration System 8.2 Vapor Refrigerant Charging 8.3 Liquid Refrigerant Charging 8.4 Weighing Refrigerant 8.5 Using Graduated Cylinders Summary Review Questions	
Unit 9	CALIBRATING INSTRUMENTS	100
	9.1 The Need for Calibration 9.2 Calibration 9.3 Temperature-Measuring Instruments 9.4 Pressure Test Instruments 9.5 Electrical Test Instruments 9.6 Refrigeration Leak Detection Devices 9.7 Flue-Gas Analysis Instruments 9.8 General Maintenance Summary Review Questions	
Unit 10	SAFETY	113
	10.1 Pressure Vessels and Piping 10.2 Electrical Hazards 10.3 Heat 10.4 Cold 10.5 Mechanical Equipment 10.6 Moving Heavy Objects 10.7 Using Chemicals Summary Review Questions	
SECTION 3	BASIC AUTOMATIC CONTROLS	121
Unit 11	BASIC ELECTRICITY AND MAGNETISM	121
	11.1 Structure of Matter 11.2 Movement of Electrons 11.3 Conductors 11.4 Insulators 11.5 Electricity Produced from Magnetism 11.6 Direct Current (DC) 11.7 Alternating Current (AC) 11.8 Electrical Units of Measurement 11.9 The Electrical Circuit 11.10 Making Electrical Measurements 11.11 Ohm's Law 11.12 Characteristics of Series Circuits 11.13 Characteristics of Parallel Circuits 11.14 Electrical Power 11.15 Magnetism 11.16 Inductance 11.17 Transformers 11.18 Capacitance 11.19 Electrical Measuring Instruments 11.20 Wire Sizes 11.21 Circuit Protection Devices Summary Review Questions	
Unit 12	INTRODUCTION TO AUTOMATIC CONTROLS	138
	12.1 Types of Automatic Controls 12.2 Devices That Respond to Thermal Change 12.3 The Bimetal Device 12.4 Control by Fluid Expansion 12.5 The Thermocouple 12.6 Electronic Temperature Sensing Devices Summary Review Questions	
Unit 13	SYSTEM CONTROL COMPONENTS	148
	13.1 Recognition of Control Components 13.2 Temperature Controls 13.3 Space-Temperature Controls, Low Voltage 13.4 Space-Temperature Controls, High (Line) Voltage Summary Review Questions	
Unit 14	CONTROLLING THE TEMPERATURE OF MASS	157
	14.1 Sensing the Temperature of Solids 14.2 Measuring the Temperature of Fluids 14.3 Sensing Temperature in an Airstream 14.4 Things to Remember about Sensing Devices Summary Review Questions	
Unit 15	PRESSURE-SENSING DEVICES	164
	15.1 Introduction to Pressure-Sensing Devices 15.2 High-Pressure Controls 15.3 Low-Pressure Controls 15.4 Oil-Pressure Safety Controls 15.5 Air-Pressure Controls 15.6 Gas-Pressure Switches 15.7 Devices that Control Fluid Flow and Do Not Contain Switches 15.8 Water-Pressure Regulators 15.9 Gas-Pressure Regulators Summary Review Questions	
Unit 16	TROUBLESHOOTING BASIC CONTROLS	173
	16.1 Introduction to Troubleshooting 16.2 Troubleshooting a Simple Circuit 16.3 Troubleshooting a Complex Circuit 16.4 Troubleshooting the Thermostat 16.5 Service Technician Calls 16.6 Troubleshooting Amperage in Low-Voltage Circuits 16.7 Troubleshooting Voltage in the Low-Voltage Circuit 16.8 Pictorial and Line Diagrams Summary Review Questions	
Unit 17	TROUBLESHOOTING MECHANICAL AND ELECTROMECHANICAL CONTROLS	188
	17.1 Mechanical and Electromechanical Controls 17.2 Mechanical Controls 17.3 Service Technician Calls 17.4 Electromechanical Controls 17.5 Service Technician Calls Summary Review Questions	

Unit 18 ELECTRONIC AND PROGRAMMABLE CONTROLS 193

18.1 Electronic Controls 18.2 Gas-Furnace Pilot Lights 18.3 Oil Furnaces 18.4 Air Conditioning Applications 18.5 Electronic Thermostats 18.6 Diagnostic Thermostats 18.7 Troubleshooting Electronic Controls 18.8 Troubleshooting the Electronic Thermostat 18.9 Programming the Electronic Thermostat 18.10 Power Outage and the Electronic Thermostat 18.11 Service Technician Calls Summary Review Questions

SECTION 4 COMMERCIAL REFRIGERATION 207

Unit 19 THE COMPRESSION CYCLE, EVAPORATORS 207

19.1 Refrigeration 19.2 Refrigeration and Food Preservation 19.3 Refrigeration as Air Conditioning 19.4 Temperature Ranges of Refrigeration 19.5 Boiling and Condensing 19.6 The Evaporator and Boiling Temperature 19.7 Removing Moisture 19.8 Heat Exchange Characteristics of the Evaporator 19.9 Types of Evaporators 19.10 Evaporator Evaluation 19.11 Latent Heat in the Evaporator 19.12 The Flooded Evaporator 19.13 Dry-Type Evaporator Performance 19.14 Superheat 19.15 Hot Pull-Down (Excessively Loaded Evaporator) 19.16 Pressure Drop in Evaporators 19.17 Liquid Cooling Evaporators 19.18 Evaporators For Low-Temperature Application 19.19 Defrost of Accumulated Moisture Summary Review Questions

Unit 20 CONDENSERS 222

20.1 The Condenser 20.2 Water-Cooled Condensers 20.3 Tube Within a Tube Condensers 20.4 Mineral Deposits 20.5 Cleanable Condensers 20.6 Shell and Coil 20.7 Shell and Tube Condensers 20.8 Wastewater Systems 20.9 Refrigerant-to-Water Temperature Relationship 20.10 Recirculated Water Systems 20.11 Cooling Towers 20.12 Natural-Draft Towers 20.13 Forced-Draft Towers 20.14 Evaporative Condensers 20.15 Air-Cooled Condensers 20.16 Inside the Condenser 20.17 Condensing Refrigerant and the Ambient Air Relationship 20.18 The Condenser and Low Ambient Conditions 20.19 Head-Pressure Control 20.20 Utilizing the Condenser's Superheat 20.21 Heat Reclaim 20.22 Condenser Evaluation Summary Review Questions

Unit 21 COMPRESSORS 239

21.1 The Function of the Compressor 21.2 Types of Compressors 21.3 Compressor Components 21.4 Belt-Drive Mechanism Characteristics 21.5 Direct-Drive Compressor Characteristics 21.6 The Rotary Compressor 21.7 Reciprocating Compressor Efficiency 21.8 Liquid in the Compressor Cylinder 21.9 System Maintenance and Compressor Efficiency Summary Review Questions

Unit 22 EXPANSION DEVICES 258

22.1 Expansion Devices 22.2 Thermostatic Expansion Valve 22.3 Thermostatic Expansion Valve Components 22.4 The Valve Body 22.5 The Diaphragm 22.6 Needle and Seat 22.7 The Spring 22.8 The Sensing Bulb and Transmission Tube 22.9 Types of Bulb Charge 22.10 The Liquid Charge Bulb 22.11 The Cross Liquid Charge Bulb 22.12 The Vapor Charge Bulb 22.13 The Cross Vapor Charge Bulb 22.14 Functioning Example of a TXV (Thermostatic Expansion Valve) 22.15 TXV Response to Load Changes 22.16 TXV Valve Selection 22.17 Pressure Limiting TXV 22.18 Servicing the TXV 22.19 Sensing-Element Installation 22.20 The Solid-State Expansion Valve 22.21 The Automatic Expansion Valve 22.22 Automatic Expansion Valve Response to Load Changes 22.23 Special Considerations for the TXV and Automatic Expansion Valve 22.24 The Capillary Tube Expansion Device 22.25 Operating Charge for the Capillary Tube System Summary Review Questions

Unit 23 SPECIAL REFRIGERATION SYSTEM COMPONENTS 277

23.1 The Four Basic Components 23.2 Mechanical Controls 23.3 Two-Temperature Controls 23.4 Evaporator Pressure Control 23.5 Multiple Evaporators 23.6 Two-Temperature Valve 23.7 Crankcase Pressure Regulator 23.8 Adjusting the CPR Valve 23.9 Relief Valves 23.10 Low Ambient Controls 23.11 Fan Cycling Head-Pressure Control 23.12 Fan Speed Control for Controlling Head Pressure 23.13 Air Volume Control for Controlling Head Pressure 23.14 Condenser Flooding for Controlling Head Pressure 23.15 Electrical Controls 23.16 The Solenoid Valve 23.17 Pressure Switches 23.18 The

Low-Pressure Switch	23.19 The Low-Pressure Control Applied as a Thermostat	23.20 The High-Pressure Control
23.21 The Low Ambient Fan Control	23.22 The Oil Safety Switch	
23.23 The Defrost Cycle	23.24 Medium Temperature Refrigeration	23.25 Random or Off-Cycle Defrost
23.26 Planned Defrost	23.27 Low-Temperature Evaporator Design	
23.28 Defrost Using Internal Heat (Hot Gas Defrost)	23.29 External Heat Type of Defrost	
23.30 Refrigeration Accessories	23.31 The Receiver	23.32 The King Valve on the Receiver
23.33 Filter-Driers	23.34 Refrigerant Sight Glasses	23.35 Liquid Refrigerant Distributor
23.36 The Heat Exchanger	23.37 Suction Line Accumulator	23.38 The Suction Line Filter-Drier
23.39 The Suction Service Valve	23.40 The Discharge Service Valve	
23.41 Refrigeration Service Valves	23.42 The Diaphragm Valve	23.43 The Ball Valve
23.44 The Oil Separator	23.45 Pressure Access Ports	Summary Review Questions

Unit 24 APPLICATION OF REFRIGERATION SYSTEMS 301

24.1 Application Decisions	24.2 Reach-In Refrigeration Merchandising	24.3 Self-Contained Reach-In Fixtures
24.4 Remote Condensing Unit Equipment	24.5 Individual Condensing Units	
24.6 Multiple Evaporators and Single-Compressor Applications	24.7 Multiple Medium-Sized Compressors	
24.8 Evaporator Temperature Control	24.9 Interconnecting Piping in Multiple-Evaporator Installations	24.10 Temperature Control of the Fixture
24.11 The Evaporator and Merchandising	24.12 Chest-Type Display Fixtures	24.13 Refrigerated Shelves
24.14 Closed-Type Chest Fixtures	24.15 Controlling Sweating on the Cabinet of Fixtures	
24.16 Maintaining Store Ambient Conditions	24.17 Walk-In Refrigeration	24.18 Knock-Down Walk-In Coolers
24.19 Walk-In Cooler Doors	24.20 Evaporator Location in a Walk-In Cooler	24.21 Condensate Removal
24.22 Refrigeration Piping	24.23 Package Refrigeration for Walk-In Coolers	24.24 Ice-Making Equipment
24.25 Making Cube Ice	24.26 Making Flake Ice	24.27 Making Cylinder Type Ice
24.28 Package-Ice Machines	24.29 Beverage Coolers	Summary Review Questions

Unit 25 TROUBLESHOOTING AND TYPICAL OPERATING CONDITIONS FOR COMMERCIAL REFRIGERATION 319

25.1 Organized Troubleshooting	25.2 Troubleshooting High-Temperature Applications
25.3 Troubleshooting Medium-Temperature Applications	25.4 Troubleshooting Low-Temperature Applications
25.5 Typical High-Pressure Conditions	25.6 Typical Air-Cooled Condenser Operating Conditions
25.7 Calculating the Correct Head Pressure for Air-Cooled Equipment	25.8 Typical Operating Conditions for Water-Cooled Equipment
25.9 Typical Operating Conditions for Wastewater Condenser Systems	25.10 Typical Operating Conditions for Recirculated Water Systems
25.11 Six Typical Problems	25.12 Low Refrigerant Charge
25.13 Refrigerant Overcharge	25.14 Inefficient Evaporator
25.15 Inefficient Condenser	25.16 Refrigerant Flow Restrictions
25.17 Inefficient Compressor	25.18 Compressor Vacuum Test
25.19 Closed Loop Compressor Running Bench Test	25.20 Compressor Closed Loop Running Field Test
25.21 Compressor Running Test in the System	25.22 Service Technician Calls
Summary	Review Questions

SECTION 5 ELECTRIC MOTORS 363

Unit 26 TYPES OF ELECTRIC MOTORS 363

26.1 Uses of Electric Motors	26.2 Parts of an Electric Motor	26.3 Electric Motors and Magnetism
26.4 Starting Windings	26.5 Determining a Motor's Speed	26.6 Starting and Running Characteristics
26.7 Power Supplies for Electric Motors	26.8 Single-Phase Open Motors	26.9 Split-Phase Motors
26.10 The Centrifugal Switch	26.11 The Electronic Relay	26.12 Capacitor-Start Motor
26.13 Capacitor-Start, Capacitor-Run Motor	26.14 Permanent Split-Capacitor Motor	26.15 The Shaded-Pole Motor
26.16 Three-Phase Motor	26.17 Single-Phase Hermetic Motor	26.18 The Potential Relay
26.19 The Current Relay	26.20 Positive-Temperature-Coefficient Start Device	26.21 Two-Speed Compressor Motors
26.22 Special-Application Motors	26.23 Three-Phase Motor Compressors	26.24 Cooling Electric Motors
Summary	Review Questions	

Unit 27 APPLICATION OF MOTORS 380

27.1 Motor Applications	27.2 The Power Supply	27.3 Electrical Motor Working Conditions
27.4 The Insulation Type or Class	27.5 Types of Bearings	27.6 Motor Mounting Characteristics
27.7 Motor Drives	Summary	Review Questions

Unit 28	MOTOR STARTING	395
	28.1 Introduction to Motor Control Devices 28.2 Run Load and Locked-Rotor Current 28.3 The Relay 28.4 The Contactor 28.5 Motor Starters 28.6 Motor Protection 28.7 Inherent Motor Protection 28.8 External Motor Protection 28.9 Service Factor 28.10 National Electrical Code Standards 28.11 Temperature-Sensing Devices 28.12 Magnetic Overload Devices 28.13 Restarting The Motor Summary Review Questions	
Unit 29	TROUBLESHOOTING ELECTRIC MOTORS	405
	29.1 Electric Motor Troubleshooting 29.2 Mechanical Motor Problems 29.3 Removing Drive Assemblies 29.4 Belt Tension 29.5 Pulley Alignment 29.6 Electrical Problems 29.7 Open Windings 29.8 Shorted Motor Windings 29.9 Short Circuit to Ground (Frame) 29.10 Motor Starting Problems 29.11 Checking Capacitors 29.12 Identification of Capacitors 29.13 Wiring and Connectors 29.14 Troubleshooting Hermetic Motors 29.15 Service Technician Calls Summary Review Questions	
SECTION 6	AIR CONDITIONING (HEATING AND HUMIDIFICATION)	417
Unit 30	ELECTRIC HEAT	417
	30.1 Introduction 30.2 Portable Electric Heating Devices 30.3 Radiant Heating Panels 30.4 Electric Baseboard Heating 30.5 Unit Heaters 30.6 Electric Hydronic Boilers 30.7 Central Forced-Air Electric Furnaces 30.8 Automatic Control for Forced-Air Electric Furnaces 30.9 The Low-Voltage Thermostat 30.10 Controlling Multiple Stages 30.11 Wiring Diagrams 30.12 Control Circuits for Forced-Air Electric Furnaces 30.13 Fan Motor Circuits 30.14 Contactors to Control Electric Furnaces 30.15 Service Technician Calls Summary Review Questions	
Unit 31	GAS HEAT	431
	31.1 Introduction to Gas-Fired Forced-Hot-Air Furnaces 31.2 Types of Furnaces 31.3 Gas Fuels 31.4 Gas Combustion 31.5 The Gas Burner 31.6 Gas Regulator 31.7 Gas Valve 31.8 The Solenoid Valve 31.9 The Diaphragm Valve 31.10 Heat-Motor-Controlled Valve 31.11 Automatic Combination Gas Valve 31.12 Pilots 31.13 Safety Devices at the Standing Pilot 31.14 Thermocouples and Thermopiles 31.15 The Bimetallic Safety Device 31.16 Liquid-Filled Remote Bulb 31.17 The Manifold 31.18 The Orifice 31.19 The Burners 31.20 The Heat Exchanger 31.21 The Fan Switch 31.22 The Limit Switch 31.23 Venting 31.24 Gas Piping 31.25 Gas-Furnace Wiring Diagrams 31.26 Trouble- shooting Techniques 31.27 Troubleshooting the Safety Pilot-Proving Device—The Thermocouple 31.28 Glow-Coil Ignition Circuit 31.29 Troubleshooting the Glow-Coil Circuit 31.30 Troubleshooting the Gas-Valve Circuit 31.31 Spark-to-Pilot Ignition 31.32 Trouble- shooting Spark-Ignition Pilot Lights 31.33 Direct-Spark Ignition (DSI) 31.34 High-Efficiency Gas Furnaces 31.35 Combustion Efficiency 31.36 Service Technician Calls Summary Review Questions	
Unit 32	OIL HEAT	472
	32.1 Introduction to Oil-Fired Forced-Warm-Air Furnaces 32.2 Physical Characteristics 32.3 Fuel Oils 32.4 Preparation of Fuel Oil for Combustion 32.5 Gun-Type Oil Burners 32.6 Oil Furnace Wiring Diagrams 32.7 Stack Switch Safety Control 32.8 Cad Cell Safety Control 32.9 Fuel Oil Supply Systems 32.10 Combustion Chamber 32.11 Heat Exchanger 32.12 Service Procedures 32.13 Combustion Efficiency 32.14 Service Technician Calls Summary Review Questions	
Unit 33	HYDRONIC HEAT	504
	33.1 Introduction to Hydronic Heating 33.2 Boiler 33.3 Limit Control 33.4 Water Regulating Valve 33.5 Pressure Relief Valve 33.6 Air Cushion Tank or Expansion Tank 33.7 Zone Control Valves 33.8 Centrifugal Pumps 33.9 Finned-Tube Baseboard Units 33.10 Balancing Valves 33.11 Flow Control Valves 33.12 Horizontal and Vertical Forced-Air- Discharge Unit Heaters 33.13 Hydronic Heating Piping Systems 33.14 Tankless Domestic Hot-Water Heaters 33.15 Service Technician Calls Summary Review Questions	

Unit 34	SOLAR HEAT	517
	34.1 Stored Solar Energy 34.2 Direct Solar Energy 34.3 Passive Solar Design 34.4 Active Solar Systems 34.5 Direct and Diffuse Radiation 34.6 Solar Constant 34.7 Declination Angle 34.8 Solar Collectors 34.9 Active Solar Air Space Heating 34.10 Air Solar Collectors 34.11 Liquid Solar Collectors 34.12 Collector Location and Positioning 34.13 Storage 34.14 Sensible Heat Storage 34.15 Latent Heat Storage 34.16 Air-Based Sensible-Heat Storage 34.17 Liquid-Based Storage Systems 34.18 Steel Tanks 34.19 Fiberglass Tanks 34.20 Concrete Tanks 34.21 Insulation Requirements 34.22 Latent-Heat Storage Systems 34.23 Other System Components 34.24 Valves 34.25 Expansion Tanks 34.26 Insulation 34.27 Solar Space-Heating Systems Summary Review Questions	
Unit 35	WOOD HEAT	540
	35.1 Organic Makeup and Characteristics of Wood 35.2 Creosote 35.3 Types of Wood-Burning Appliances 35.4 Wood-Burning Stoves 35.5 Catalytic Combustors 35.6 Combustion in the Catalytic Combustor 35.7 A Typical Stove Design with a Catalytic Element 35.8 Operating a Stove with a Catalytic Element 35.9 Causes of a Catalytic Failure 35.10 Combustor Life 35.11 Air Pollution Control 35.12 General Operating and Safety Procedures 35.13 Location of the Stove 35.14 Heat Distribution 35.15 Makeup Air 35.16 Safety Hazards 35.17 Installation Procedures 35.18 Smoke Detectors 35.19 Fireplace Inserts 35.20 Add-on Wood-Burning Furnaces 35.21 Dual-Fuel Furnaces 35.22 Factory-Built Chimneys 35.23 Cleaning the Chimney, Connector Pipe, and Heat Exchanger Summary Review Questions	
Unit 36	HUMIDIFICATION	555
	36.1 Relative Humidity 36.2 Humidification 36.3 Humidifiers 36.4 Humidifier Media 36.5 Atomizing Humidifiers 36.6 Self-Contained Humidifiers 36.7 Pneumatic Atomizing Systems 36.8 Sizing Humidifiers 36.9 Installation 36.10 Service, Troubleshooting, and Preventive Maintenance Summary Review Questions	
SECTION 7 AIR CONDITIONING (COOLING)		563
Unit 37	COMFORT	563
	37.1 Comfort 37.2 Food Energy and the Body 37.3 Body Temperature 37.4 The Comfort Chart 37.5 Psychrometrics 37.6 Moisture in Air 37.7 Superheated Gases in Air 37.8 Humidity 37.9 Dry-Bulb and Wet-Bulb Temperatures 37.10 Dew-Point Temperature 37.11 The Psychrometric Chart 37.12 Total Heat Summary Review Questions	
Unit 38	REFRIGERATION APPLIED TO AIR CONDITIONING	575
	38.1 Refrigeration 38.2 Structural Heat Gain 38.3 Evaporative Cooling 38.4 Refrigerated Cooling or Air Conditioning 38.5 The Evaporator 38.6 The Job of the Evaporator 38.7 Design Conditions 38.8 Evaporator Application 38.9 The Compressor 38.10 Compressor Speeds (rpm) 38.11 Compressor Mountings 38.12 Rebuilding the Hermetic Compressor 38.13 The Water-Cooled Compressor 38.14 The Rotary Compressor 38.15 The Condenser 38.16 Side-Air-Discharge Condensing Units 38.17 Top-Air-Discharge Condensers 38.18 Condenser Coil Design 38.19 High-Efficiency Condensers 38.20 Cabinet Design 38.21 Expansion Devices 38.22 Air-Side Components 38.23 Installation Procedures Summary Review Questions	
Unit 39	AIR DISTRIBUTION AND BALANCE	592
	39.1 Conditioning Equipment 39.2 Correct Air Quantity 39.3 The Forced-Air System 39.4 The Blower 39.5 System Pressures 39.6 Air-Measuring Instruments for Duct Systems 39.7 Types of Fans 39.8 Types of Fan Drives 39.9 The Supply Duct System 39.10 The Plenum System 39.11 The Extended Plenum System 39.12 The Reducing Plenum System 39.13 The Perimeter Loop System 39.14 Duct Materials 39.15 Galvanized Steel Duct 39.16 Fiberglass Duct 39.17 Spiral Metal Duct 39.18 Flexible Duct 39.19 Combination Duct Systems 39.20 Duct Air Movement 39.21 Balancing Dampers 39.22 Duct Insulation 39.23 Blending the Conditioned Air with Room Air 39.24 The Return-Air Duct System 39.25 Sizing Duct for Moving Air 39.26 Measuring Air Movement for Balancing 39.27 The Air Friction Chart Summary Review Questions	

Unit 40 INSTALLATION

623

40.1 Three Crafts Involved in Installation 40.2 Square and Rectangular Ducts 40.3 Duct Section Fasteners, Square Duct and Rectangular Duct 40.4 Round Metal Duct Systems 40.5 Insulation for Metal Duct 40.6 Ductboard Systems 40.7 Flexible Duct 40.8 Electrical Installation 40.9 The Power Supply 40.10 Sizing the Conductors 40.11 Low-Voltage Circuits 40.12 Installation of the Refrigeration System 40.13 Package Systems 40.14 Air-to-Air Package Equipment Installation 40.15 Vibration Isolation 40.16 Duct Connections for Package Equipment 40.17 Installing the Split System 40.18 The Evaporator Section 40.19 Service Access 40.20 Condensate Drain Piping 40.21 Condensing Unit 40.22 Air Circulation and Installation 40.23 Electrical and Piping Considerations 40.24 Service Accessibility 40.25 Water Drainage from Natural Sources 40.26 Solar Influence 40.27 Placing a Condensing Unit for Best Appearance 40.28 Installing Refrigerant Piping 40.29 The Refrigerant Charge 40.30 The Line Set 40.31 Tubing Leak Test and Evacuation 40.32 Altered Line-Set Lengths 40.33 Precharged Line Sets (Quick-Connect Line Sets) 40.34 Altered Precharged Line Sets 40.35 Piping Advice 40.36 Equipment Startup Summary Review Questions

Unit 41 CONTROLS

645

41.1 Controls for Air Conditioning 41.2 Prime Movers—Compressors and Fans 41.3 Low-Voltage Controls 41.4 Some History of Residential Central Air Conditioning 41.5 Economics of Equipment Design 41.6 Operating Controls for Older Air-Cooled Systems 41.7 Safety Controls for Older Air-Cooled Systems 41.8 Operating Controls for Modern Equipment 41.9 Safety Controls for Modern Equipment 41.10 Loss-of-Charge Protection 41.11 The Working Control Package 41.12 Electronic Controls and Air Conditioning Equipment Summary Review Questions

Unit 42 TYPICAL OPERATING CONDITIONS

657

42.1 Mechanical Operating Conditions 42.2 Humidity and the Load 42.3 System Component Relationships Under Load Changes 42.4 Evaporator Operating Conditions 42.5 High Evaporator Load and a Cool Condenser 42.6 Grades of Equipment 42.7 Documentation With the Unit 42.8 Establishing a Reference Point on Unknown Equipment 42.9 Metering Devices for High Efficiency Equipment 42.10 Typical Electrical Operating Conditions 42.11 Matching the Unit to the Correct Power Supply 42.12 Starting the Equipment With the Correct Data 42.13 Finding a Point of Reference for an Unknown Motor Rating 42.14 Determining the Compressor's Running Amperage 42.15 Compressors Operating at Full-Load Current 42.16 High Voltage, The Compressor, and Current Draw 42.17 Current Draw and the Two-Speed Compressor Summary Review Questions

Unit 43 TROUBLESHOOTING

670

43.1 Troubleshooting Categories 43.2 Mechanical Troubleshooting 43.3 Gage Manifold Usage 43.4 High Side Gage 43.5 When to Connect the Gages 43.6 Gage Port Valves for Schrader Valve 43.7 Low-Side Gage Readings 43.8 High-Side Gage Readings 43.9 High-Efficiency Condenser Pressures 43.10 Temperature Readings 43.11 Types of Temperature Readings 43.12 Inlet Air Temperatures 43.13 Evaporator Outlet Temperatures 43.14 Suction-Line Temperatures 43.15 Discharge-Line Temperatures 43.16 Liquid-Line Temperatures 43.17 Charging Procedures in the Field 43.18 Fixed-Bore Metering Devices—Capillary Tube and Orifice Type 43.19 Field Charging the Thermostatic Expansion Valve System 43.20 Electrical Troubleshooting 43.21 Verifying the Power Supply 43.22 Component Selection for Troubleshooting 43.23 Compressor Overload Problems 43.24 Compressor Electrical Checkup 43.25 Troubleshooting the Circuit Electrical Protectors—Fuses and Breakers 43.26 Service Technician Calls Summary Review Questions

SECTION 8 ALL-WEATHER SYSTEMS

693

Unit 44 ELECTRIC, GAS AND OIL HEAT WITH ELECTRIC AIR CONDITIONING

693

44.1 Comfort All Year 44.2 Five Processes for Conditioning Air 44.3 Add-on Air Conditioning 44.4 Insulation For Existing Duct Work 44.5 Evaluation of an Existing Duct System 44.6 The Air Distribution System 44.7 Summer Versus Winter Air Quantity 44.8 Control Wiring for Summer and Winter 44.9 Two Low-Voltage Power Supplies

44.10 Phasing Two Low-Voltage Transformers	44.11 Adding a Fan Relay	44.12 New All-Weather Systems
44.13 All-Weather Split Systems	44.14 Package or Self-Contained All-Weather Systems	44.15 Wiring The All-Weather System
44.16 Servicing The All-Weather System	Summary	Review Questions

Unit 45 HEAT PUMPS

703

45.1 Reverse-Cycle Refrigeration	45.2 Heat Sources for Winter	45.3 The Four-Way Valve
45.4 Types of Heat Pumps, Air-to-Air	45.5 Water-to-Air Heat Pumps	45.6 Removing Heat From Manufacturing Processes
45.7 Removing Heat From the Ground	45.8 Solar-Assisted Heat Pumps	45.9 The Air-to-Air Heat Pump
45.10 System Identification	45.11 Refrigerant Line Identification	45.12 Metering Devices
45.13 Thermostatic Expansion Valves	45.14 The Capillary Tube	45.15 Combinations of Metering Devices
45.16 Electronic Expansion Valves	45.17 Liquid-Line Accessories	45.18 Orifice Metering Devices
45.19 Application of the Air-to-Air Heat Pump	45.20 Auxiliary Heat	45.21 Balance Point
45.22 Coefficient of Performance	45.23 Split-System Air-to-Air Heat Pump	45.24 The Indoor Unit
45.25 Air Temperature of the Conditioned Air	45.26 The Outdoor Unit Installation	45.27 Package Air-to-Air Heat Pumps
45.28 Controls for the Air-to-Air Heat Pump	45.29 Space-Temperature Control	45.30 Cooling Cycle Control
45.31 Space Heating Control	45.32 Emergency Heat Control	45.33 The Defrost Cycle
45.34 Instigating the Defrost Cycle	45.35 Terminating the Defrost Cycle	45.36 Electronic Control of Defrost
45.37 Auxiliary Heat	45.38 Servicing the Air-to-Air Heat Pump	45.39 Troubleshooting the Electrical System
45.40 Typical Electrical Problems	45.41 Troubleshooting Mechanical Problems	45.42 Some Typical Mechanical Problems
45.43 Troubleshooting the Four-Way Valve	45.44 Troubleshooting the Compressor	45.45 Checking the Charge
45.46 Special Applications for Heat Pumps	45.47 Maximum Heat Pump Running Time	45.48 Add-on Heat Pump to Existing Electric Furnace
45.49 Service Technician Calls	Summary	Review Questions

APPENDIXES

743

Appendix I	LOAD ESTIMATION PROCEDURES	744
	Load Estimation Survey	744
	Whole-House Worksheet, Add-On and Replacement (Existing Construction) Short Form	748
	Whole-House Worksheet (New Construction) Short Form	753
	Computer Worksheet, Short Form (Whole House)	759
	Computer Worksheet, Long Form (Room-by-Room)	765
Appendix II	DOMESTIC APPLIANCES	773
	Unit A Domestic Refrigerators	773
	Unit B Domestic Freezers	825
	Unit C Room Air Conditioning	851
Appendix III	TEMPERATURE CONVERSION TABLE	879
Appendix IV	ELECTRICAL SYMBOLS CHART	881
GLOSSARY		882
INDEX		894

Section One

Theory of Heat



THEORY

OBJECTIVES

After studying this unit, you should be able to

- define temperature.
- make general comparisons between Fahrenheit and Celsius scales.
- describe molecular motion at absolute 0.
- define the British thermal unit.
- describe heat flow between substances of different temperatures.
- explain the transfer of heat by conduction, convection, and radiation.
- discuss sensible heat, latent heat, and specific heat.
- state the atmospheric pressure at sea level and explain why it varies at different elevations.
- describe two types of barometers.
- explain psig and psia as they apply to pressure gages.

1.1 TEMPERATURE

The word “temperature” is used in everyday discussions or descriptions about comfort, weather, and food preparation. It is used in many conversations and decision-making processes by people who still do not know exactly how far-reaching the word is or what it really means.

Temperature can be thought of as a description of the level of heat. For now, heat can be thought of as energy in the form of molecules in motion. The starting point of temperature is, therefore, the starting point of molecular motion. To describe this in more usable

terms, we will describe some more familiar points of reference.

Most people know that the freezing point of water is 32 degrees Fahrenheit (32°F) and that the boiling point is 212 degrees Fahrenheit (212°F). These points are commonly indicated on a thermometer.

Early thermometers were of glass-stem types operating on the theory that when the substance in the bulb was heated it would expand and rise up in the tube, Figure 1-1. Mercury and alcohol are still commonly used today for this application. More information

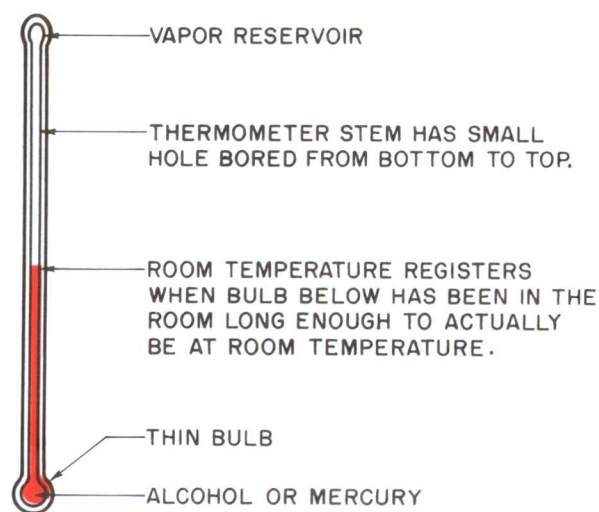


Figure 1-1. Thermometer.

about temperature measurement is found in the section on automatic controls.

We must qualify the statement that water boils at 212°F. Pure water boils at precisely 212°F at sea level when the atmosphere is 68°F. This qualification concerns the relationship of the earth's atmosphere to the boiling point and will be covered in detail later in this section in the discussion on pressure. The statement that water boils at 212°F at sea level when the atmosphere is 68°F is important because these are standard conditions that will be applied to actual practice in later units.

Pure water has a freezing point of 32°F. Obviously the temperature can go lower than 32°F, but the question is, how much lower?

The theory is that molecular motion stops at -460°F. See Figure 1-2 for an illustration of the levels of heat or molecular motion shown on a thermometer scale. This is theoretical because molecular motion has never been totally stopped. The complete stopping of molecular motion will be recorded as absolute zero. This has been calculated to be -460°F. Scientists have actually come within a few degrees of reaching absolute zero.

Temperature can also be expressed in degrees Centigrade or, more commonly, Celsius. The weather forecaster often uses the term "Celsius." Celsius and Fahrenheit both express the level of heat, but they do it in different terms, Figure 1-2.

Temperature has been expressed in everyday terms up to this point. It is equally important in the air conditioning, heating, and refrigeration industry to describe temperature in terms engineers and scientists use. Performance ratings of equipment are established

in terms of *absolute* temperature. Equipment is rated to establish criteria for comparing equipment performance. In other words, different manufacturers make similar claims about their products. We can use the equipment rating to evaluate these claims. The Fahrenheit absolute scale is called the *Rankine* scale (named for its inventor W. J. M. Rankine), and the Celsius absolute scale is known as the *Kelvin* scale (named for the scientist, Lord Kelvin). Absolute temperature scales begin where molecular motion starts; they use 0 as the starting point. For instance, 0 on the Fahrenheit absolute scale is called absolute zero or 0° Rankine (0°R). Similarly, 0 on the Celsius absolute scale is called absolute zero or 0° Kelvin (0 K). See Figure 1-3.

The Fahrenheit, Celsius and the Rankine, Kelvin scales are used interchangeably to describe equipment and fundamentals of this industry. Memorization is not very important. To be able to work back and forth from degrees Fahrenheit to degrees Rankin, with Celsius and Kelvin surfacing from time to time, is too much to ask. A working knowledge of these scales and a ready reference table are more practical. Figure 1-3 shows how these four scales are related. The world that we live in accounts for only a small portion of the total temperature spectrum. The thermometer scale illustrated in Figure 1-4 shows some examples of how typical temperatures compare.

Our earlier statement that temperature describes the level of heat or molecular motion can now be explained. As a substance becomes warmer, the molecular motion, and therefore the temperature, increases, Figure 1-5.

1.2 INTRODUCTION TO HEAT

The laws of thermodynamics can help us to understand what heat is all about. One of these laws states that heat can neither be created nor destroyed. This means that all of the heat that the world experiences is not created but is merely converted to usable heat from something that is already here. This heat can also be accounted for when it is transferred from one substance to another.

Heat can now be more fully explored by using temperature as one of the describing factors. Remember, temperature describes the level of heat with reference to no heat. The term used to describe the quantity of heat is known as the *British thermal unit* (Btu). This term explains how much heat is contained in a substance. The rate of heat consumption can be determined by adding time to the picture, but more on this later.

The Btu is defined as the amount of heat required to raise the temperature of 1 lb of water 1°F. For example, when 1 lb of water (about 1 pint) is heated from 68° to 69°F, 1 Btu of heat energy is absorbed into the water, Figure 1-6. To actually measure how much heat is absorbed in a process like this, we need

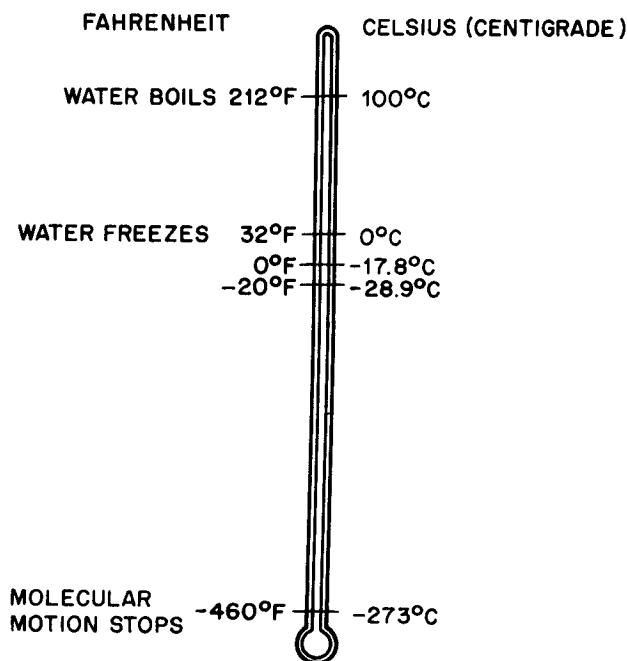


Figure 1-2. Fahrenheit scale compared to Celsius scale.

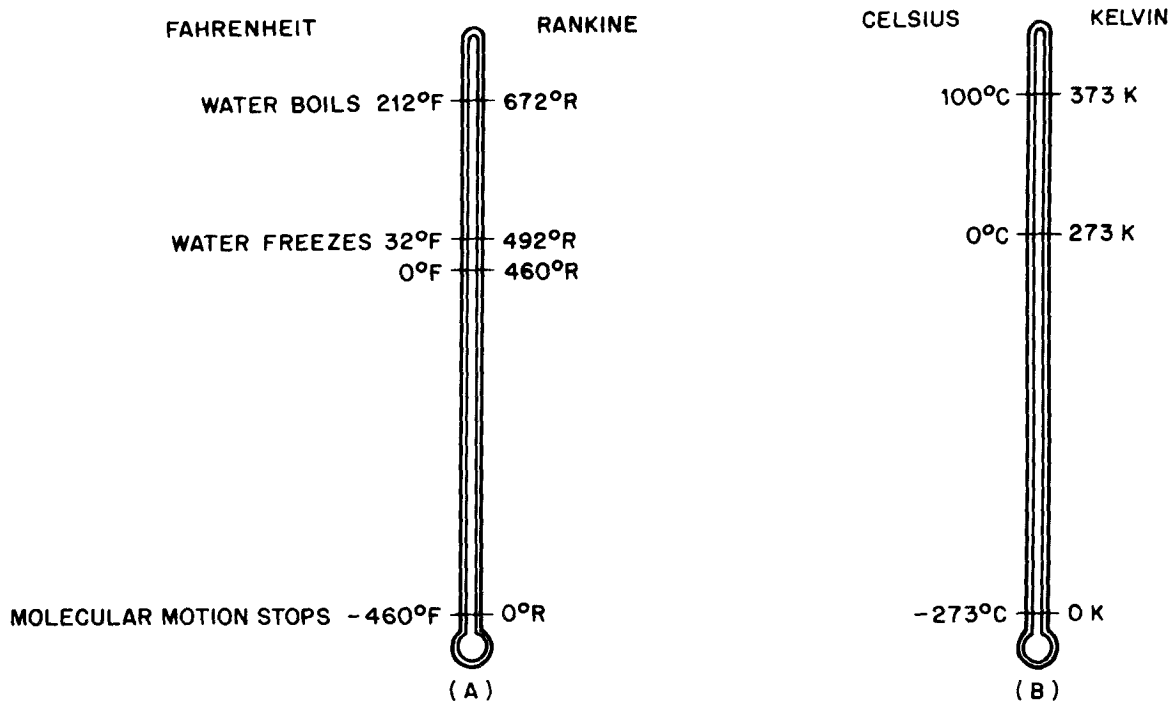


Figure 1-3. (A) Fahrenheit and Rankine thermometer. (B) Celsius and Kelvin thermometer.

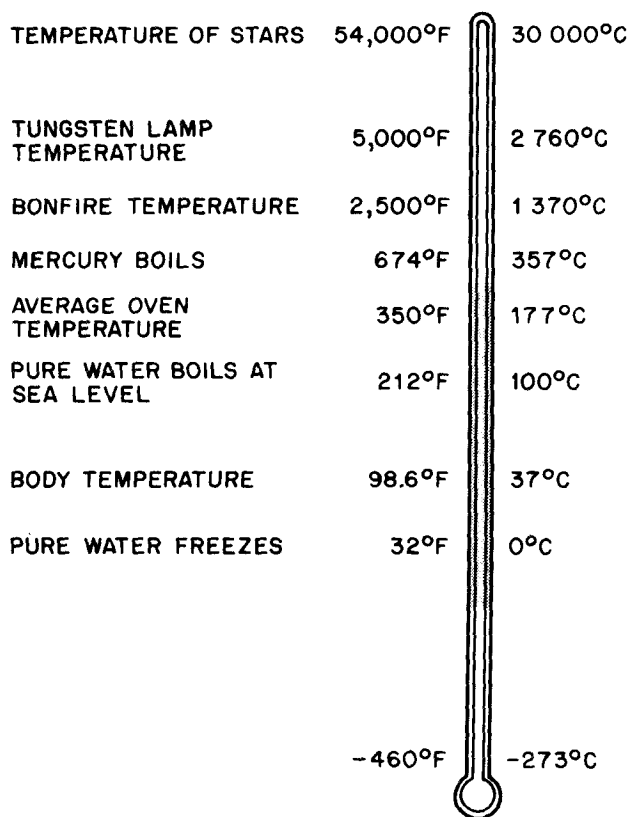


Figure 1-4. Civilization is generally exposed to a comparatively small range of temperatures.

an instrument of laboratory quality. This instrument is called a *calorimeter*. Notice the similarity to the word "calorie," the food word for energy.

Heat flows naturally from a warmer substance to a cooler substance. Rapidly moving molecules in the warmer substance give up some of their energy to the slower-moving molecules in the cooler substance. The warmer substance cools because the molecules have slowed. The cooler substance becomes warmer because the molecules are moving somewhat faster.

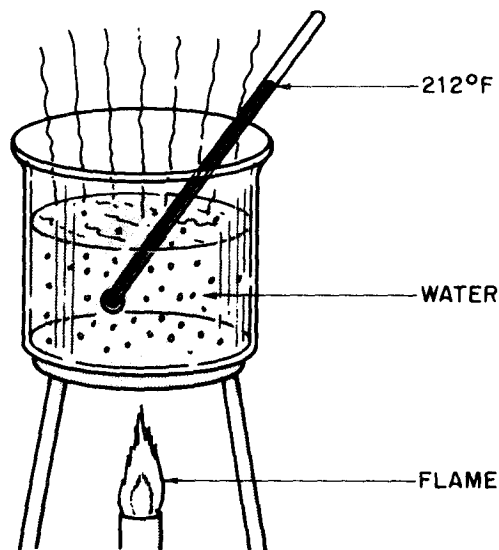


Figure 1-5. The water in the pot boils because the molecules move faster when heat is applied.

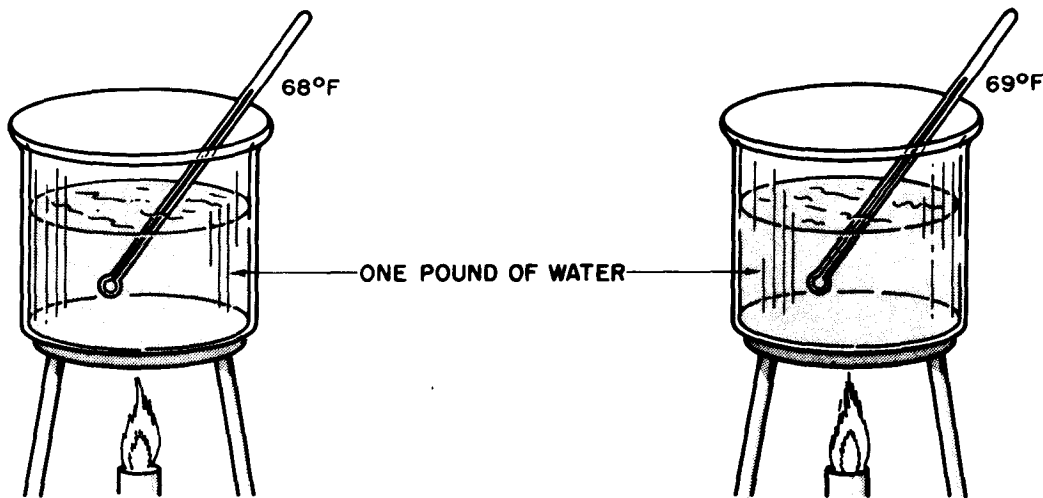


Figure 1-6. 1 British thermal unit (Btu) of heat energy is required to heat 1 lb of water from 68°F to 69°F.

The following example will illustrate the difference in the amount or quantity of heat compared to the level of heat. One tank of water weighing 10 lb (slightly more than 1 gallon) is heated to a temperature level of 200°F. A second tank of water weighing 100,000 lb (slightly more than 12,000 gallons) is heated to 175°F. It is easy to imagine that the 10-lb tank will cool to room temperature much faster than the 100,000-lb tank. The temperature difference of 25°F is not very much, but the cool-down time is much longer for the 100,000-lb tank, Figure 1-7.

A comparison using water is always helpful in showing the level verses the quantity of heat. A well with 200 ft of water would not have nearly as much water as a large lake with 25 ft of water. The depth of water (in feet) tells us the level of water, but it in no way expresses the quantity (gallons) of water.

In practical terms, each piece of heating equipment is rated according to the amount of heat it will

produce. If the equipment had no such rating, it would be difficult for a buyer to intelligently choose the correct appliance.

A gas or oil furnace used to heat a home has the rating permanently printed on a nameplate. Either furnace would be rated in Btu per hour, which is a *rate* of energy consumption. Later, this rate will be used to calculate the amount of fuel required to heat a house or a structure. For now, it is sufficient to say that if one needs a 75,000-Btu/h furnace to heat a house on the coldest day, a furnace rated at 75,000 Btu/h should be chosen. If not, the house will begin to get cold on any day the temperature falls below the capacity of the furnace.

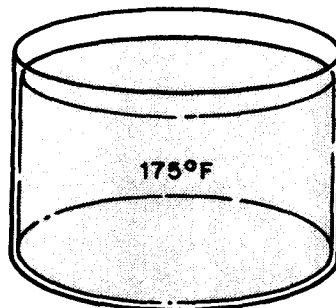
1.3 CONDUCTION

Conduction heat transfer can be explained as the energy actually traveling from one molecule to another.

ROOM TEMPERATURE (70°F)



10-POUND TANK OF WATER
IS HEATED TO 200°F
(ABOUT 1 GALLON)



100,000-POUND TANK OF WATER
IS HEATED TO 175°F
(ABOUT 12,000 GALLONS)

Figure 1-7. The smaller tank will cool to room temperature first because there is a smaller quantity of heat.