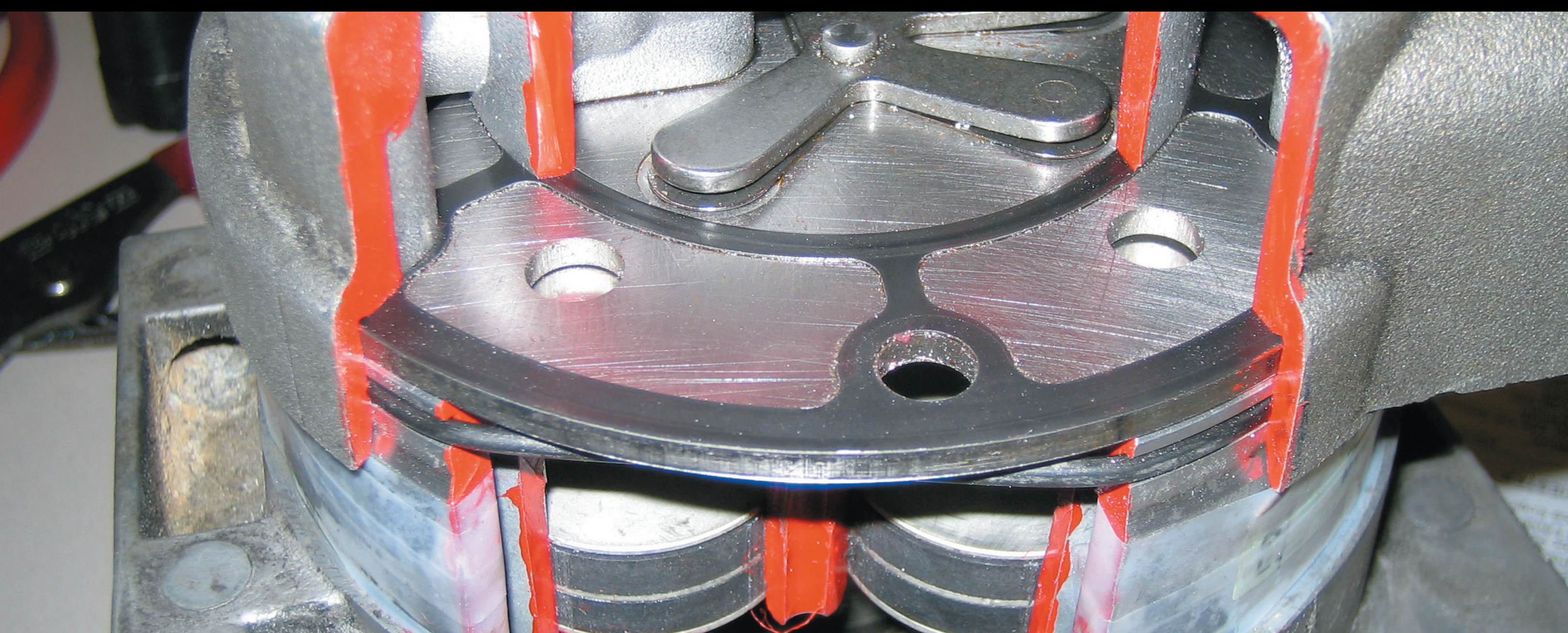
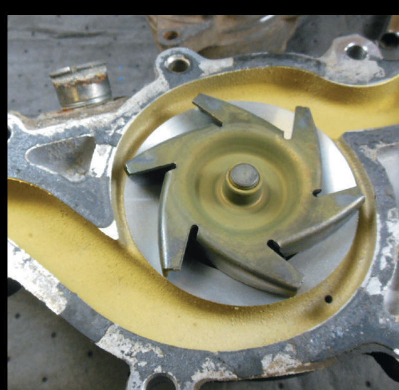
Automotive Heating and Air Conditioning

Eighth Edition

James D. Halderman





AUTOMOTIVE HEATING AND AIR CONDITIONING

EIGHTH EDITION

James D. Halderman

Pearson

330 Hudson Street, NY NY 10013

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Printer/Binder: RR Donnelley, Menasha
Cover Printer: Phoenix Color
Text Font: Helvetica Neue LT W1G

Library of Congress Cataloging-in-Publication Data

Name: Halderman, James D.
Title: Automotive heating and air conditioning / James D. Halderman
Description: Eighth edition. | Boston : Pearson Education, [2017] | Includes index.
Identifiers: LCCN 2016040962 | ISBN 9780134603698 (alk. paper)
Subjects: LCSH: Automobiles—Heating and ventilation. | Automobiles—Air conditioning.
Classification: LCC TL271 .B57 2017 | DDC 629.2/772—dc23 LC record available at https://lccn.loc.gov/2016040962

10 9 8 7 6 5 4 3 2 1

Pearson

ISBN 10: 0-13-460369-9
ISBN 13: 978-0-13-460369-8

PREFACE

PROFESSIONAL TECHNICIAN SERIES Part of the Pearson Automotive Professional Technician Series, the eighth edition of *Automotive Heating and Air Conditioning* represents the future of automotive textbooks. The series is a full-color, media-integrated solution for today's students and instructors. The series includes textbooks that cover all eight areas of ASE certification, plus additional titles covering common courses. The series is peer reviewed for technical accuracy.

UPDATES TO THE EIGHTH EDITION As a result of requests from automotive instructors and reviewers, the new eighth edition has been totally updated including:

1. New chapter organization and expanded coverage
2. Updated throughout to match the latest ASE/NATEF tasks
3. Expanded content on R-1234yf refrigerant (Chapter 4)
4. Over 50 new full color line drawings and photos make the subject come alive
5. Case studies added to selected chapters that include the "three Cs" (Complaint, Cause and Correction)
6. New chapter on engine coolants (**Chapter 7**)
7. New chapter on HVAC system inspection procedures (**Chapter 13**)
8. New content on sealant filters (**Chapter 15**)
9. All systems and components are described throughout with the following format to make learning complex systems easier:
    - Purpose and Function
    - Parts and Operation
    - Diagnosis and Service
10. All terms used adhere to the SAE J1930 standard

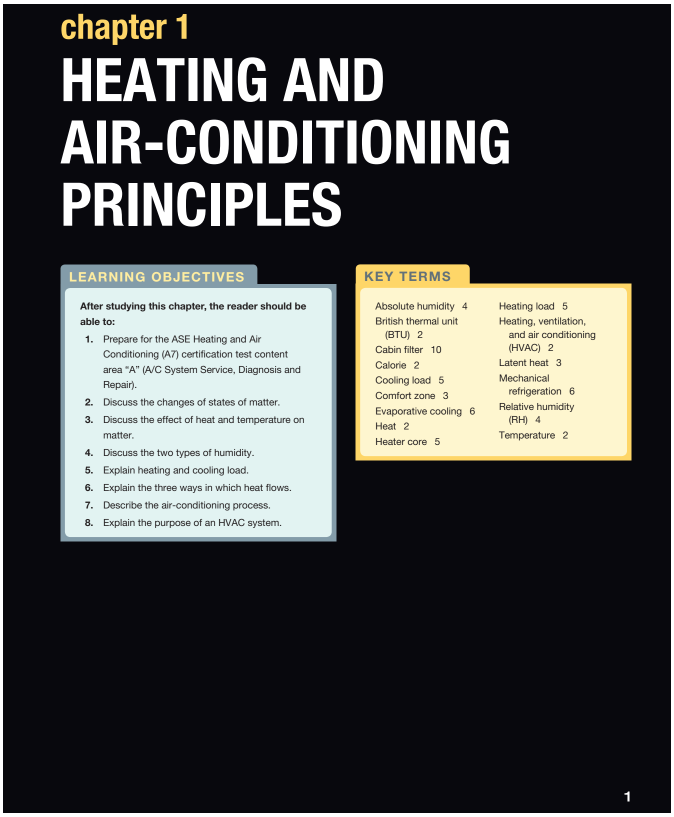
ASE AND NATEF CORRELATED NATEF certified programs need to demonstrate that they use course material that covers NATEF and ASE tasks. All Professional Technician textbooks have been correlated to the appropriate ASE and NATEF task lists. These correlations can be found in Appendix 2.

A COMPLETE INSTRUCTOR AND STUDENT SUPPLEMENTS PACKAGE All Professional Technician textbooks are accompanied by a full set of instructor and student supplements. Please see page vi for a detailed list of supplements.

A FOCUS ON DIAGNOSIS AND PROBLEM SOLVING The Professional Technician Series has been developed to satisfy the need for a greater emphasis on problem diagnosis. Automotive instructors and service managers agree that students and beginning technicians need more training in diagnostic procedures and skill development. To meet this need and demonstrate how real-world problems are solved, "Real World Fix" features are included throughout and highlight how real-life problems are diagnosed and repaired.

The following pages highlight the unique core features that set the Professional Technician Series book apart from other automotive textbooks.

IN-TEXT FEATURES



chapter 1

HEATING AND AIR-CONDITIONING PRINCIPLES

LEARNING OBJECTIVES

After studying this chapter, the reader should be able to:

1. Prepare for the ASE Heating and Air Conditioning (A7) certification test content area “A” (A/C System Service, Diagnosis and Repair).
2. Discuss the changes of states of matter.
3. Discuss the effect of heat and temperature on matter.
4. Discuss the two types of humidity.
5. Explain heating and cooling load.
6. Explain the three ways in which heat flows.
7. Describe the air-conditioning process.
8. Explain the purpose of an HVAC system.

KEY TERMS

Absolute humidity 4
British thermal unit (BTU) 2
Cabin filter 10
Calorie 2
Cooling load 5
Comfort zone 3
Evaporative cooling 6
Heat 2
Heater core 5
Heating load 5
Heating, ventilation, and air conditioning (HVAC) 2
Latent heat 3
Mechanical refrigeration 6
Relative humidity (RH) 4
Temperature 2

1

LEARNING OBJECTIVES AND KEY TERMS appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE and NATEF tasks.

TECH TIP

Be Sure to Always Use a Fan Shroud

A fan shroud forces the fan to draw air through the radiator. If a fan shroud is not used, then air is drawn from around the fan and will reduce the airflow through the radiator. Many overheating problems are a result of not replacing the factory shroud after engine work or body repair work to the front of the vehicle.

TECH TIPS feature real-world advice and “tricks of the trade” from ASE-certified master technicians.

Case Study

Cabin Filter Fault

The owner of a 2008 Ford Escape complained that the air-conditioning system was not cooling the inside of the vehicle and there seemed to be no airflow from the dash vents yet the blower motor could be heard running. A quick visual inspection of the cabin air with access under the hood showed that the cabin filter was almost completely blocked with paper, leaves, and debris. The vehicle had almost 80,000 miles on the odometer and the way it looked, the air filter had never been replaced. Most vehicle manufacturers recommend replacement of the cabin air filter about every three years or every 36,000 miles. Replacing the cabin air filter restored proper operation of the A/C system.

Summary:

Complaint—Customer complained of a lack of airflow from the dash vents.

Cause—A partially clogged cabin filter.

Correction—Replacement of the cabin filter restored proper airflow from the dash vents.

CASE STUDIES present students with actual automotive scenarios and show how these common (and sometimes uncommon) problems were diagnosed and repaired.

FREQUENTLY ASKED QUESTION

What Are U Codes?

The “U” diagnostic trouble codes were at first “undefined” but are now network-related codes. Use the network codes to help pinpoint the circuit or module that is not working correctly. Some powertrain-related faults are due to network communications errors and therefore can be detected by looking for “U” diagnostic trouble codes (DTCs).

FREQUENTLY ASKED QUESTIONS are based on the author’s own experience and provide answers to many of the most common questions asked by students and beginning service technicians.

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as *prevailing torque nuts*. This means that the nut will hold its tightness or torque and not loosen with movement or vibration.

NOTES provide students with additional technical information to give them a greater understanding of a specific task or procedure.

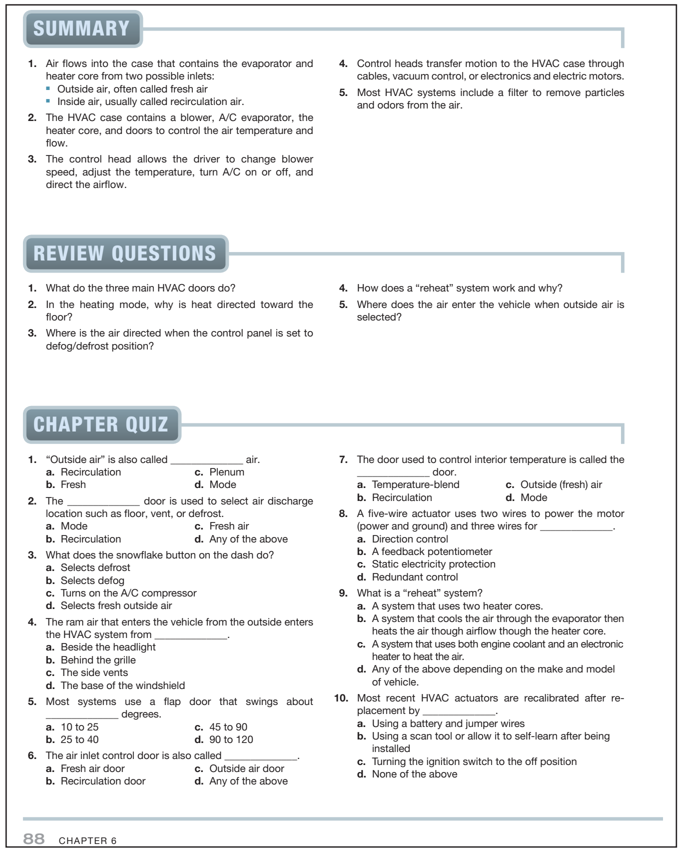
CAUTION: *Never* use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

CAUTIONS alert students about potential damage to the vehicle that can occur during a specific task or service procedure.

WARNING

An electric compressor operates at a voltage up to 230 volts, and the wires supplying this high voltage have bright orange colored insulation. This is enough voltage to cause a severe to fatal shock. DO NOT TOUCH these wires without the proper protective equipment and always follow the manufacturer's specified service procedures.

WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.



SUMMARY

1. Air flows into the case that contains the evaporator and heater core from two possible inlets:
   - Outside air, often called fresh air
   - Inside air, usually called recirculation air.
2. The HVAC case contains a blower, A/C evaporator, the heater core, and doors to control the air temperature and flow.
3. The control head allows the driver to change blower speed, adjust the temperature, turn A/C on or off, and direct the airflow.
4. Control heads transfer motion to the HVAC case through cables, vacuum control, or electronics and electric motors.
5. Most HVAC systems include a filter to remove particles and odors from the air.

REVIEW QUESTIONS

1. What do the three main HVAC doors do?
2. In the heating mode, why is heat directed toward the floor?
3. Where is the air directed when the control panel is set to defog/defrost position?
4. How does a "reheat" system work and why?
5. Where does the air enter the vehicle when outside air is selected?

CHAPTER QUIZ

1. "Outside air" is also called ____________ air.
   a. Recirculation
   b. Fresh
   c. Plenum
   d. Mode
2. The ____________ door is used to select air discharge location such as floor, vent, or defrost.
   a. Mode
   b. Recirculation
   c. Fresh air
   d. Any of the above
3. What does the snowflake button on the dash do?
   a. Selects defrost
   b. Selects defog
   c. Turns on the A/C compressor
   d. Selects fresh outside air
4. The ram air that enters the vehicle from the outside enters the HVAC system from ____________.
   a. Beside the headlight
   b. Behind the grille
   c. The side vents
   d. The base of the windshield
5. Most systems use a flap door that swings about ____________ degrees.
   a. 10 to 25
   b. 25 to 40
   c. 45 to 90
   d. 90 to 120
6. The air inlet control door is also called ____________.
   a. Fresh air door
   b. Recirculation door
   c. Outside air door
   d. Any of the above
7. The door used to control interior temperature is called the ____________ door.
   a. Temperature-blend
   b. Recirculation
   c. Outside (fresh) air
   d. Mode
8. A five-wire actuator uses two wires to power the motor (power and ground) and three wires for ____________.
   a. Direction control
   b. A feedback potentiometer
   c. Static electricity protection
   d. Redundant control
9. What is a "reheat" system?
   a. A system that uses two heater cores.
   b. A system that cools the air through the evaporator then heats the air though airflow though the heater core.
   c. A system that uses both engine coolant and an electronic heater to heat the air.
   d. Any of the above depending on the make and model of vehicle.
10. Most recent HVAC actuators are recalibrated after replacement by ____________.
    a. Using a battery and jumper wires
    b. Using a scan tool or allow it to self-learn after being installed
    c. Turning the ignition switch to the off position
    d. None of the above

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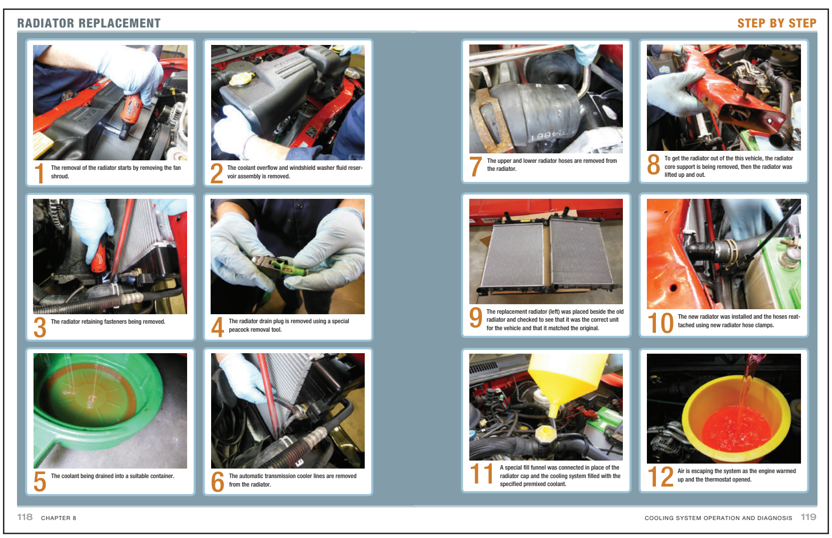
THE SUMMARY, REVIEW QUESTIONS, AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test themselves to see how much they've learned.



STEP-BY-STEP photo sequences show in detail the steps involved in performing a specific task or service procedure.

SUPPLEMENTS

RESOURCES IN PRINT AND ONLINE
Automotive Heating and Air Conditioning

Name of Supplement	Print	Online	Audience	Description
Instructor Resource Manual 0-13-460381-8		✔	Instructors	NEW! The Ultimate teaching aid: Chapter summaries, key terms, chapter learning objectives, lecture resources, discuss/ demonstrate classroom activities, and answers to the in text review and quiz questions.
TestGen 0-13-460386-9		✔	Instructors	Test generation software and test bank for the text.
PowerPoint Presentation 0-13-460384-2		✔	Instructors	Slides include chapter learning objectives, lecture outline of the test, and graphics from the book.
Image Bank 0-13-460382-6		✔	Instructors	All of the images and graphs from the textbook to create customized lecture slides.
NATEF Correlated Task Sheets – For Instructors 0-13-460385-0		✔	Instructors	Downloadable NATEF task sheets for easy customization and development of unique task sheets.
NATEF Task Sheets – For Students 0-13-460378-8	✔		Students	Study activity manual that correlates NATEF Automobile Standards to chapters and pages numbers in the text. Available to students at a discounted price when packaged with the text.
VitalSource eBook 0-13-460388-5		✔	Students	An alternative to purchasing the print textbook, students can subscribe to the same content online and save up to 50% off the suggested list price of the print text. Visit **www.vitalsource.com**

All online resources can be downloaded from the Instructor's Resource Center: **www.pearsonhighered.com/irc**

ACKNOWLEDGMENTS

A large number of people and organizations have cooperated in providing the reference material and technical information used in this text. The authors wish to express sincere thanks to the following organizations for their special contributions:

American Honda
Bill Steen, Yuba College
David Brainerd, Santa Barbara City College
Fluke Corporation
Four Seasons
Frank Allison, International Mobile Air Conditioning Association (IMACA), Executive Director
Frederick Peacock, Purdue University
General Motors Corporation
Harold Beck, Yuba City
James Johnson, Four Seasons
Lorie Homolish Apollo America Corporation
Martin Duvic, Louisiana Technical College
Mastercool
Modine Manufacturing
Nartron Corp./Smart Power Products
Neutronics Inc.
Patrick L. O'Conner, Fedco Automotive Components
Paul De Guiseppi, Mobile Air Conditioning Society (MACS)
Raytek Corp.
Red Dot Corp.
Robert Bassett, The Gates Rubber Company
Robinaire Division, SPX Corporation
Sanden International (USA)
Santech Industries
Simon Oulouhojian, Past President Mobile Air Conditioning Society (MACS)
Society of Automotive Engineers (SAE)
Stant Manufacturing
System Guard
Tom Broxholm, Skyline College
Tony Jewel, Reedley College
Toyota Motor Sales, USA

TECHNICAL AND CONTENT REVIEWERS The following people reviewed the manuscript before production and checked it for technical accuracy and clarity of presentation. Their suggestions and recommendations were included in the final draft of the manuscript. Their input helped make this textbook clear and technically accurate while maintaining the easy-to-read style that has made other books from the same authors so popular.

Tom Broxholm
Skyline College

Ron Chappell
Santa Fe Community College

Curtis Cline
Wharton County Junior College

Kenneth P. Dytrt
Pennsylvania College of Technology

Curtis Happe
Richland Community College

Chris Holley
Penn College Professor

Paul Hye
Brookdale Community College

Dr. David Gilbert
Southern Illinois University

Richard Krieger
Michigan Institute of Technology

Russell A. Leonard
Ferris State University

William Milam
Eastfield College

Justin Morgan
Sinclair Community College

Greg Pfahl
Miami-Jacobs Career College

Steve Polley
Pittsburg State University

Jeff Rehkopf
Florida State College

Michael Reimer
South Plains College

Scott Russell
Blue Ridge Community College

Eugene Talley
Southern Illinois University

Chuck Taylor
Sinclair Community College

Ken Welch
Saddleback College

Special thanks to instructional designer **Alexis I. Skriloff James.**

PHOTO SEQUENCES The author wishes to thank Chuck Taylor of Sinclair Community College in Dayton, Ohio, plus Greg Pfahl and James (Mike) Watson who helped with many of the photos. A special thanks to Randal Sedwick, Dick Krieger, Jeff Rehkopf, and Eugene Talley for their detailed and thorough review of the manuscript before publication and to Richard Reaves for all of his help. Most of all, I wish to thank Michelle Halderman for her assistance in all phases of manuscript preparation.

James D. Halderman

ABOUT THE AUTHORS

JAMES D. HALDERMAN Jim Halderman brings a world of experience, knowledge, and talent to his work. His automotive service experience includes working as a flat-rate technician, a business owner, and a professor of automotive technology at a leading U.S. community college for more than 20 years.

He has a Bachelor of Science degree from Ohio Northern University and a Master's degree in Education from Miami University in Oxford, Ohio. Jim also holds a U.S. patent for an electronic transmission control device. He is an ASE-certified Master Automotive Technician and Advanced Engine Performance (L1) ASE certified. Jim is the author of many automotive textbooks, all published by Pearson. Jim has presented numerous technical seminars to national audiences, including the California Automotive Teachers (CAT) and the Illinois College Automotive Instructor Association (ICAIA). He is also a member and presenter at the North American Council of Automotive Teachers (NACAT). Jim was also named Regional Teacher of the Year by General Motors Corporation and a member of the advisory broad for Technological Studies department at Ohio Northern University. Jim and his wife, Michelle, live in Dayton, Ohio. They have two children. You can reach Jim at:

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BRIEF CONTENTS

CONTENTS

chapter 1

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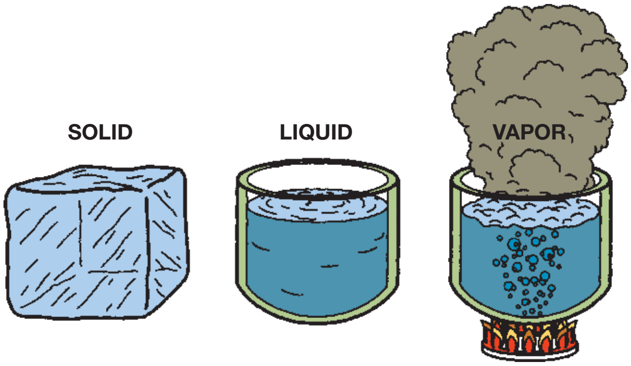


FIGURE 1–1 Water is a substance that can be found naturally in solid, liquid, and vapor states.

FREQUENTLY ASKED QUESTION

Why Is Liquid Sprayed from a Can Cold?

If a pressurized can of liquid is sprayed continuously, the can becomes cold, and so does the liquid being sprayed. The can becomes cold because the pressure in the can is reduced while spraying, allowing the liquid propellant inside the can to boil and absorb heat. The propellant vapor is further cooled as it decompresses when it hits the open air. Rapid decompression results in a rapid temperature drop.

INTRODUCTION

PURPOSE AND FUNCTION The **heating, ventilation, and air-conditioning (HVAC)** system of an automobile is designed to provide comfort for the driver and passengers. It is intended to maintain in-vehicle temperature and humidity within a range that is comfortable for the people inside and provide fresh, clean air. The air-conditioning system transfers the heat from inside the vehicle and moves it to the outside of the vehicle. The heater is needed in cold climates to prevent freezing or death.

PRINCIPLES INVOLVED On earth, matter is found in one of three different phases or states:

1. Solid
2. Liquid
3. Vapor (gas)

The state depends upon the nature of the substance, the temperature, and the pressure or force exerted on it. Water occurs naturally in all three states: solid ice, liquid water, and water vapor, depending upon the temperature and pressure. ● SEE FIGURE 1–1.

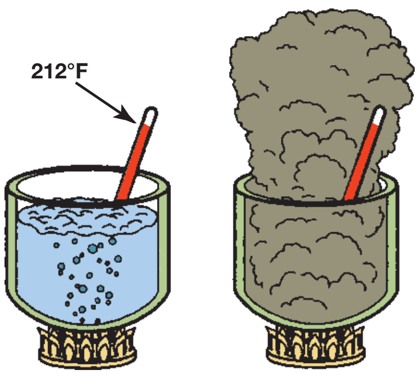
CHANGES OF STATE A solid is a substance that cannot be compressed and has strong resistance to flow. The molecules of a solid attract each other strongly, and resist changes in volume and shape.

- A substance is solid at any temperature below its melting point. Melting point is a characteristic of the substance, and is related to the temperature at which a solid turns to liquid. For water, the melting point is 32°F (0°C), which means that changes can be observed between liquid water and ice under normal weather conditions.
- A liquid is a substance that cannot be compressed. A substance in a liquid state has a fixed volume, but no definite shape.
- The boiling point is the temperature at which a liquid substance turns to vapor. For water at normal sea level conditions, the boiling point is 212°F (100°C). A vapor is a substance that can be easily compressed, has no resistance to flow, and no fixed volume. Since a vapor flows, it is considered a fluid just like liquids are.

A vapor condenses to liquid if the temperature falls below the vaporizing temperature. Again, the difference is simply whether heat is being added or taken away. Boiling point and condensation point temperatures are not fixed because they vary with pressure.

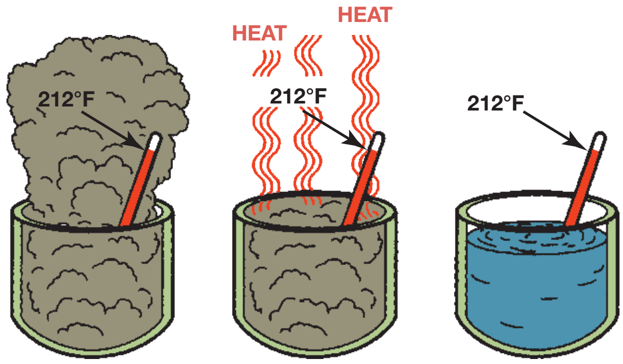
HEAT AND TEMPERATURE Molecules in a substance tend to vibrate rapidly in all directions, and this disorganized energy is called heat. The intensity of vibration depends on how much kinetic energy, or energy of motion, the atom or molecule contains. Heat and temperature are not the same.

- **Temperature** is the measure of the level of energy. Temperature is measured in degrees.
- **Heat** is measured in the metric unit called **calorie** and expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius. Heat is also measured in **British Thermal Units (BTU)**. One BTU is the heat required to raise the temperature of one pound of water 1°F at sea level. One BTU equals 252 calories.



1 GRAM WATER + 540 CALORIES = 1 GRAM VAPOR
1 POUND WATER + 970 BTUs = 1 POUND VAPOR

FIGURE 1–2 The extra heat required to change a standard amount of water at its boiling point to vapor is called latent heat of vaporization.



1 GRAM OF VAPOR – 540 CALORIES = 1 GRAM WATER
1 POUND OF VAPOR – 970 BTUs = 1 POUND WATER

FIGURE 1–3 The latent heat of vaporization that water vapor stores is released when the vapor condenses to a liquid. The temperature stays the same.

SENSIBLE HEAT Sensible heat makes sense because it can be felt and measured on a thermometer. If there is 1 lb. of water at 40°F and 1 BTU of heat is added to it, the temperature will increase to 41°F. Adding another BTU of heat will increase the temperature to 42°F and adding another 170 BTU (212–42) will increase the temperature to 212°F, the boiling point.

LATENT HEAT **Latent heat** is the "extra" heat that is needed to transform a substance from one state to another. Imagine that a solid or a liquid is being heated on a stove. When the solid reaches its melting point, or the liquid reaches its boiling point, their temperatures stop rising. The solid begins to melt, and the liquid begins to boil. This occurs without any sensible change in temperature, even though heat is still being applied from the burner. The water in the container on the stove boils at a temperature of 212°F (100°C) at sea level, for as long as any liquid water remains. As heat is further added to the water, heat will be used in changing the state of the liquid to a vapor. This extra, hidden amount of energy necessary to change the state of a substance is called latent heat. ● **SEE FIGURES 1–2 AND 1–3.**

Latent heat is important in the operation of an air-conditioning system because the cooling effect is derived from changing the state of liquid refrigerant to vapor. The liquid refrigerant absorbs the latent heat of vaporization, making the air cooler. The cooler air is then blown into the passenger compartment.

TEMPERATURE, VOLUME, AND PRESSURE OF A VAPOR Unlike a solid, vapor has no fixed volume. Increasing the temperature of a vapor, while keeping the volume confined in the same space, increases the pressure. This happens as the vibrating vapor molecules collide more and more energetically with the walls of the container. Conversely, decreasing the temperature decreases the pressure. This relationship between temperature and pressure in vapor is why a can of nonflammable refrigerant can explode when heated by a flame—the pressure buildup inside the can will eventually exceed the can's ability to contain the pressure. Increasing the pressure by compressing vapor increases the temperature. Decreasing the pressure by permitting the vapor to expand decreases the temperature.

HEAT INTENSITY Intensity of heat is important to us because if it is too cold, humans feel uncomfortable and is measured in degrees. Extremely cold temperatures can cause frostbite and hypothermia. The other end of the scale can also be uncomfortable and may cause heat stress and dehydration. Humans have a temperature **comfort zone** somewhere between 68°F and 78°F (20°C and 26°C). This comfort zone varies among individuals. ● **SEE FIGURE 1–4.**

RULES OF HEAT TRANSFER Heating and air conditioning must follow the basic rules of heat transfer. An understanding of these rules helps greatly in understanding the systems.

- Heat always flows from hot to cold. (From higher level of energy to lower level of energy.) ● **SEE FIGURE 1–5.**
- To warm a person or item, heat must be added.
- To cool a person or item, heat must be removed.
- A large amount of heat is absorbed when a liquid changes state to vapor.

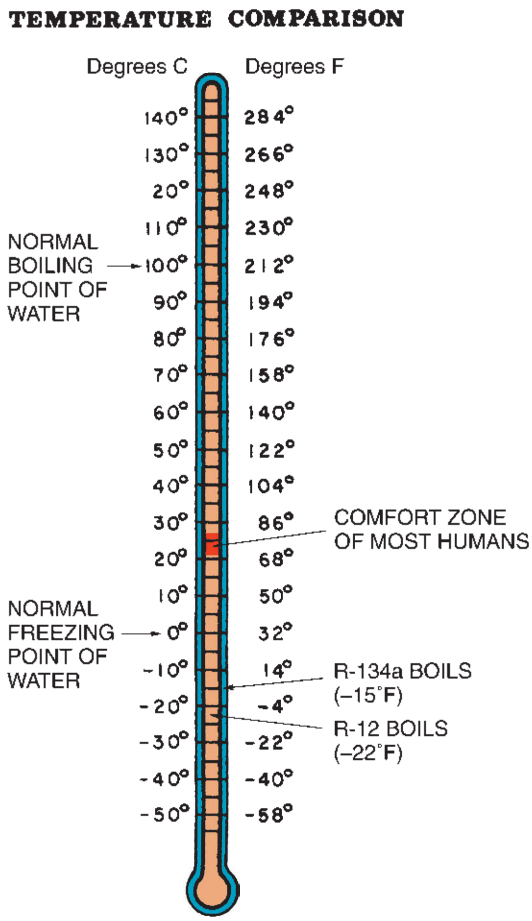


FIGURE 1–4 Heat intensity is measured using a thermometer. The two common measuring scales, Celsius and Fahrenheit, are shown here. This thermometer is also marked with water freezing and boiling and refrigerant boiling temperatures.

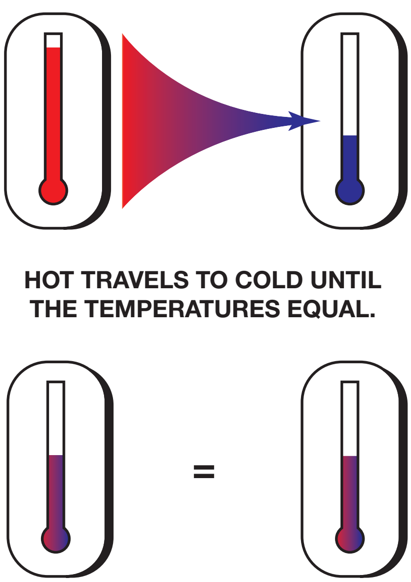


FIGURE 1–5 Heat travels from higher temperature (higher energy level), to lower temperature (lower energy level).

TECH TIP

Quick and Easy Temperature Conversion

Temperature in service information and on scan tools is often expressed in degrees Celsius, which is often confusing to those used to temperature expressed in Fahrenheit degrees. A quick and easy way to get an *approximate* conversion is to take the degrees in Celsius, double it, and add 25.

For example,

Celsius × 2 + 25 = approximate Fahrenheit degrees:

0°C × 2 = 0 + 25 = 25°F (actual = 32°F)
10°C × 2 = 20 + 25 = 45°F (actual = 50°F)
15°C × 2 = 30 + 25 = 55°F (actual = 59°F)
20°C × 2 = 40 + 25 = 65°F (actual = 68°F)
25°C × 2 = 50 + 25 = 75°F (actual = 77°F)
30°C × 2 = 60 + 25 = 85°F (actual = 86°F)
35°C × 2 = 70 + 25 = 95°F (actual = 95°F)
40°C × 2 = 80 + 25 = 105°F (actual = 104°F)
45°C × 2 = 90 + 25 = 115°F (actual = 113°F)
50°C × 2 = 100 + 25 = 125°F (actual = 122°F)

The simplest way to convert between the Fahrenheit and Celsius scales accurately is to use a conversion chart or use an app on a smart phone.

- A large amount of heat is released when a vapor changes state to a liquid.
- Compressing a gas concentrates the heat and increases the temperature.

HUMIDITY Humidity refers to water vapor present in the air. The level of humidity depends upon the amount of water vapor present and the temperature of the air. The amount of water vapor in the air tends to be higher near lakes or the ocean, because more water is available to evaporate from their surfaces. In desert areas with little open water, the amount of water vapor in the air tends to be low.

- **Absolute humidity** is the measure of the amount of moisture (water vapor) in the air regardless of the temperature.
- **Relative humidity (RH)** is the percentage of how much moisture is present in the air compared to how much moisture the air is capable of holding at that temperature.

Relative humidity is commonly measured with a *hygrometer* or a *psychrometer*. A hygrometer depends on a sensitive

FIGURE 1–6 A combination meter that measures and displays both the temperature and the humidity is useful to use when working on air-conditioning systems.

element that expands and contracts, based on the humidity. Hygrometers typically resemble a clock, with the scale reading from 0% to 100% relative humidity. ● **SEE FIGURE 1–6.**

HEATING AND COOLING LOAD

HEATING LOAD **Heating load** is the term used when additional heat is needed. The actual load is the number of BTUs or calories of heat energy that must be added. In a home or office, burning fuel is the usual way to generate heat using coal, gas, or oil as a fuel. In most vehicles, the heat is provided by the heated coolant from the engine cooling system. This coolant is typically at a temperature of 190°F to 205°F (88°C to 98°C) when the engine reaches its normal operating temperature. ● **SEE FIGURE 1–8.**

In most vehicles, heated coolant is circulated through a heat exchanger, called a **heater core**. Air is circulated through the heater core, where it absorbs heat. Then it is blown into the passenger compartment, where the heat travels on to warm the car interior and occupants. The air from the blower motor moves the heat from the heater core to the passengers.

COOLING WITH ICE One way to move heat, called **cooling load**, is with a block of ice. A substantial amount of

FREQUENTLY ASKED QUESTION

What Is a Sling Pyschrometer?

A psychrometer is a measuring instrument used to measure relative humidity. It uses two thermometers, one of which has the bulb covered in a cotton wick soaked in distilled water from a built in reservoir. The wick keeps the bulb of the "wet thermometer" wet so that it can be cooled by evaporation. Sling psychrometers are spun round in the air a certain number of times. Water evaporates from the cotton wick at a rate inversely proportional to the relative humidity of the air.

- Faster if the humidity is low.
- Slower if the humidity is high.

The "dry thermometer" measures the air temperature.

- The higher the relative humidity, the closer the readings of the two thermometers.
- The lower the humidity, the greater the difference in temperature of the two thermometers.

The different temperatures indicated by the wet and dry thermometers are compared to values given in a chart, which gives the relative humidity. While a sling psychrometer is still used, most technicians use an electronic instrument to measure relative humidity. ● **SEE FIGURE 1–7.**

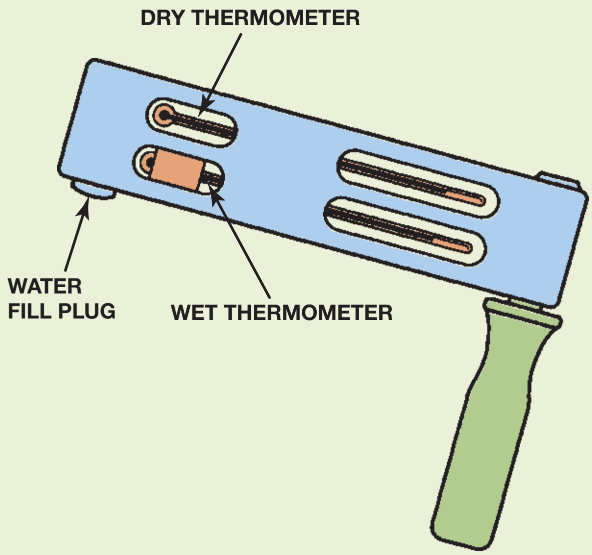


FIGURE 1–7 A sling psychrometer is used to measure relative humidity.

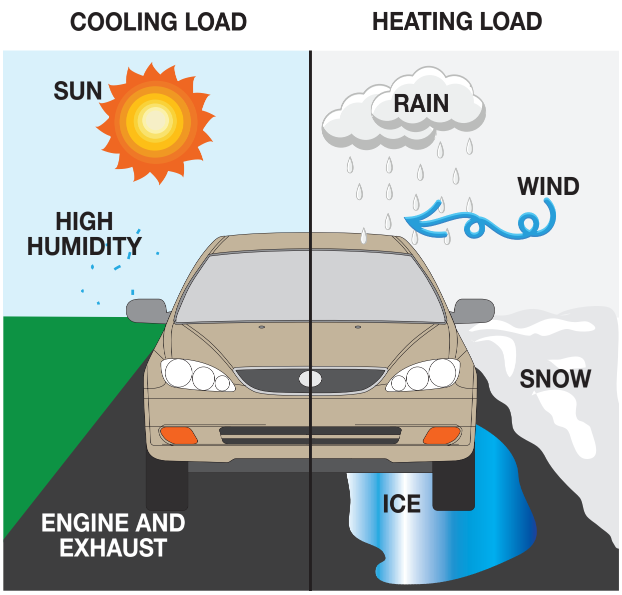


FIGURE 1–8 Winter presents a heat load where heat must be added for comfort (right). Summer presents a cooling load.

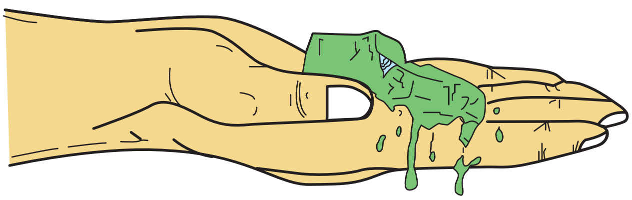


FIGURE 1–9 Ice has a cooling effect because of latent heat of fusion which means that it absorbs heat as it melts.

FIGURE 1–10 At one time, evaporative coolers were used to cool car interiors. Air forced through a water-wetted mesh produces evaporation and a cooling effect.

latent heat is required to change the state of the solid ice into a liquid:

- 144 BTU per lb. (80 calories per gram).
- A 50-lb. block of ice represents 50 × 144, or 7,200 BTU, of cooling power when it changes from 50 lb. of solid at 32°F to 50 lb. of liquid at 32°F.

In the early days of air conditioning, the term *ton* was commonly used. A ton of air conditioning was the amount of heat it took to melt a ton of ice: 2,000 × 144, or 288,000 BTU. ● **SEE FIGURE 1–9.**

EVAPORATIVE COOLING A method of cooling that works well in areas of low humidity is evaporation of water, commonly called **evaporative cooling**. If water is spread thinly over the extremely large area of a meshed cooler pad and air is blown across it, the water evaporates. For every pound of water that evaporates, 970 BTU (540 calories per gram) of heat is absorbed. This is the latent heat of evaporation, just as when it is boiled. This is a natural process and uses only the energy required by the blower to circulate the air through the cooler pads and on to the space to be cooled. Disadvantages of evaporative coolers, often called "swamp coolers" includes:

- increases the relative humidly
- not effective in areas of high humidity because the water does not evaporate rapidly enough to be efficient.

At one time, window-mounted evaporative coolers were used in cars. They were not very popular because they were unattractive and worked well only in dry areas. ● **SEE FIGURE 1–10.**

MECHANICAL COOLING A third way to handle a cooling load is by the use of **mechanical refrigeration**, which is called air conditioning. This system also uses evaporation of a liquid and the large amount of heat required for evaporation. The refrigerant boils so that it changes from liquid to gas, but it is condensed back to gas using an engine or electrically powered compressor to move the refrigerant and to increase its pressure in the system. ● **SEE FIGURE 1–11.**

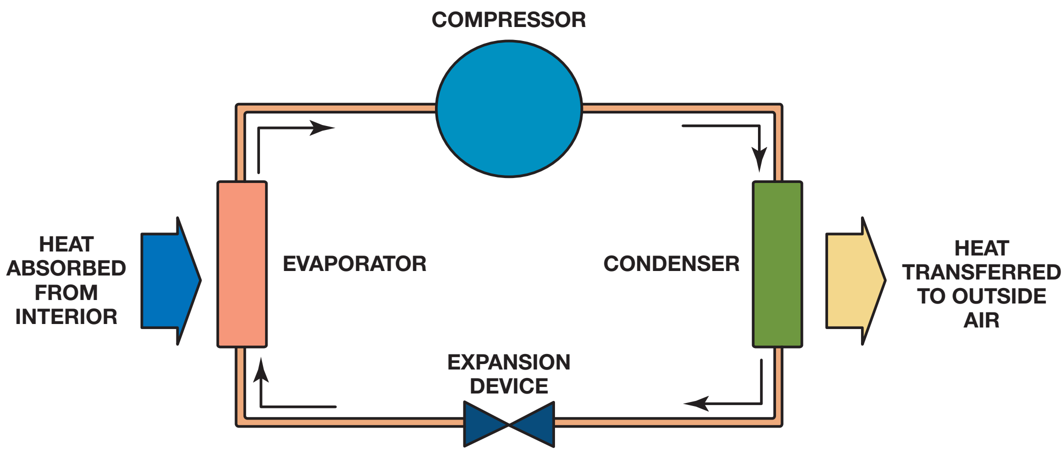


FIGURE 1–11 Heat, from in-vehicle cabin air, causes the refrigerant to boil in the evaporator (left). The compressor increases the pressure and moves refrigerant vapor to the condenser, where the heat is transferred to ambient air. This also causes the vapor to return to liquid form.

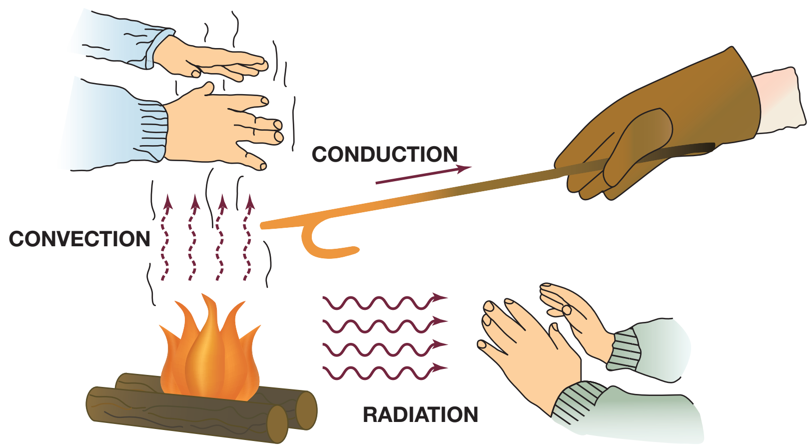


FIGURE 1–12 Heat can be moved from the source by convection, conduction, or radiation.

HEAT MOVEMENT

Heat can travel through one or more of three paths as it moves from hot to cold:

1. conduction
2. convection
3. radiation ● **SEE FIGURE 1–12.**

CONDUCTION The simplest heat movement method is conduction, by which heat travels through a medium such as a solid or liquid, moving from one molecule of the material to the next. For example, if one end of wire is heated, the heat will travel through the material itself and will be transferred through to the other end of the wire. Some materials (most of the metals) are good heat conductors. Copper and aluminum are among the best of the commonly used metals, so most heat exchangers (radiators, evaporators, and condensers) use copper or aluminum.

- Some materials, such as wood, are poor heat conductors.
- Some materials, such as Styrofoam, conduct heat so poorly that they are called insulators. Most good insulators incorporate a lot of air or gaseous material in their structure because air is a poor conductor of heat.

CONVECTION Convection is a process of transferring heat by moving the heated medium, usually air or a liquid. An example of convection is the engine cooling system. Coolant is heated in the water jackets next to the cylinders and combustion chambers. Then the coolant is pumped to the radiator, where the heat is transferred to the air traveling through the radiator. Convection also occurs in the interior of the vehicle when air is circulated past the driver and passengers

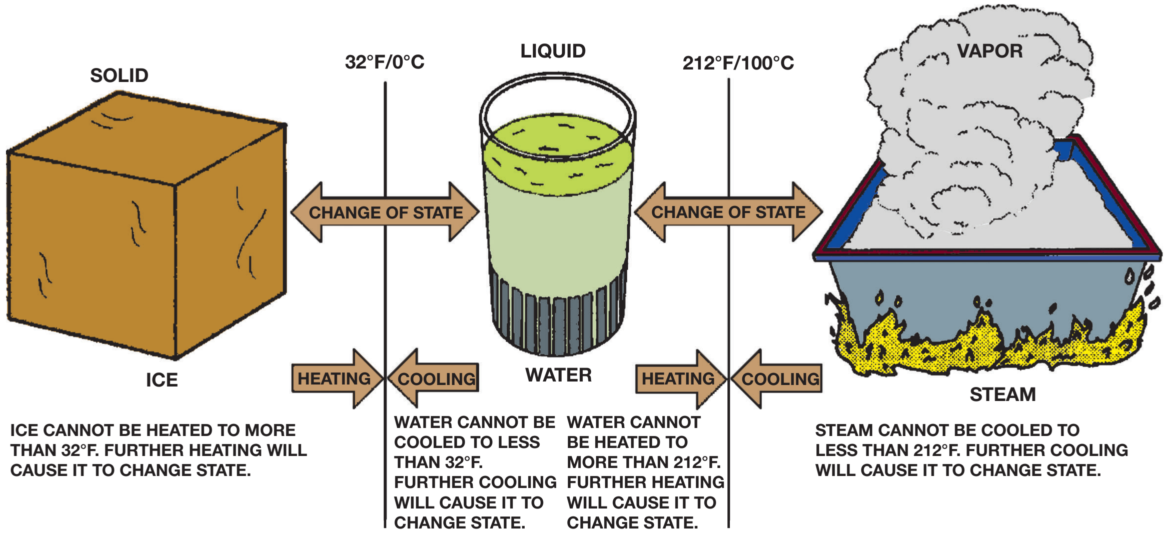


FIGURE 1–13 Matter can change state by adding or removing heat.

to pick up heat and moved to the evaporator, where the heat is transferred to the evaporator fins. The evaporator fins are cooler, so heat is transferred easily.

RADIATION Heat can travel through heat rays and pass from one location to another without warming the air through which it passes. The best example of this is the heat from the sun, which passes through cold space and warms our planet and everything it shines on. Radiant heat can pass from any warmer object through air to any cooler object. It is affected by the color and texture of the heat emitter, where the heat leaves, and the collector, where the heat is absorbed. Dark, rough surfaces make better heat emitters and collectors than light-colored, smooth surfaces.

NOTE: At one time, California Highway Patrol cars were painted all black. Painting the tops white benefited the patrol officers by lowering the in-vehicle temperature significantly.

AIR-CONDITIONING PROCESS

CHANGING THE STATE OF THE REFRIGERANT The air-conditioning process works using a fluid, called *refrigerant,* which continuously changes state from liquid to gas and back to liquid.

Most states of matter can be changed from one state to another by adding or removing heat. ● **SEE FIGURE 1–13.**

Molecules are the building blocks for all things that can be seen or felt. Molecules are combinations of atoms, which are in turn made up of electrons, neutrons, and protons. The protons are in the center, or nucleus, of the atom and the electrons travel in an orbit around them. There are about 100 basic elements or atoms, each having a different atomic number, that combine with other elements to make the many, varied molecules. The atomic number of an element is based on the number of electrons and protons in that element. The periodic table of elements seen in most chemistry laboratories shows the relationship of these elements.

Water molecules, for example, are called H_2O. This is a combination of a single oxygen atom and two hydrogen atoms. Hydrogen has an atomic number of 1 (1 proton and 1 electron), and oxygen has an atomic number of 8 (8 electrons and 8 protons). ● **SEE FIGURE 1–14.** The three states of water are well known and include:

1. Solid ice
2. Liquid water
3. Vapor (gaseous)

SOLID Solid matter has a definite shape and substance. Solids exert pressure in only one direction, and that is downward because of gravity. For example, ice is the solid form of water, and will hold its shape, and is cold. Water is normally a solid at temperatures below 32°F (0°C), which is the normal freezing point. The electrons in the molecule's atoms are still orbiting around the protons, but the movement has been slowed because much of the heat energy has been removed. ● **SEE FIGURE 1–15.**

LIQUID Adding heat to most solids causes them to reach their melting point. It is the same material, but heat energy has broken the molecular bond and the matter becomes fluid. Fluid

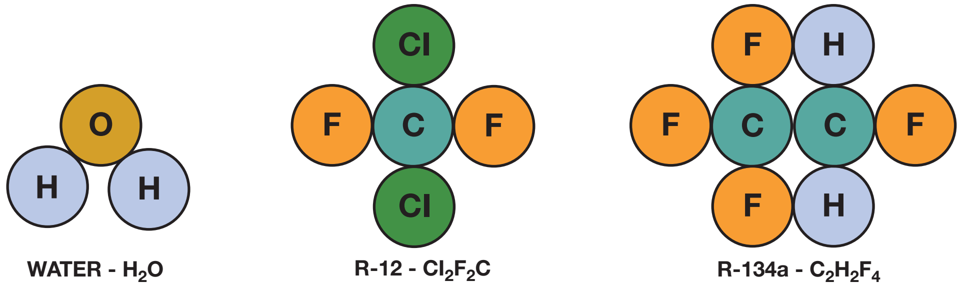


FIGURE 1–14 A water molecule contains two oxygen atoms and one hydrogen atom. R-12 is a combination of one carbon, two chlorine, and two fluorine atoms. R-134a is a combination of two carbon, four fluorine, and two hydrogen atoms.

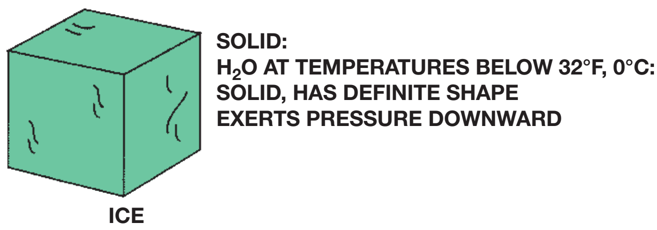


FIGURE 1–15 Ice is a solid form of water with a low temperature and slow molecular action.

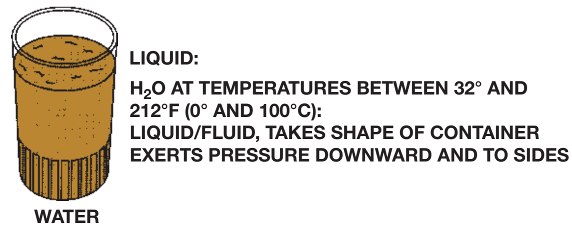


FIGURE 1–16 Water is warmer than ice and can flow to take the shape of any container.

has no shape and it takes the shape of its container. Liquids can flow through a pipe or hose and can be pumped such as by the air-conditioning compressor.

Water is normally a liquid between 32°F and 212°F (0°C and 100°C). The molecules are same as ice, but heat energy has increased the movement of the electrons. ● **SEE FIGURE 1–16.**

GAS When heat is added to most liquids, it produces gas as the liquids boil. It is the same material, but the heat energy has broken the molecular bonds still further so that the molecules have no shape at all and have expanded so much that they have very little weight. A gas molecule exerts pressure in every direction. Gases can also be pumped through hoses and pipes, making them easy to move through the air-conditioning (A/C) system.

At temperatures above 212°F (100°C), water normally boils to become a gas, called *steam*. Again, the molecules are the same as water or ice, but heat energy has greatly increased molecular movement. ● **SEE FIGURE 1–17.**

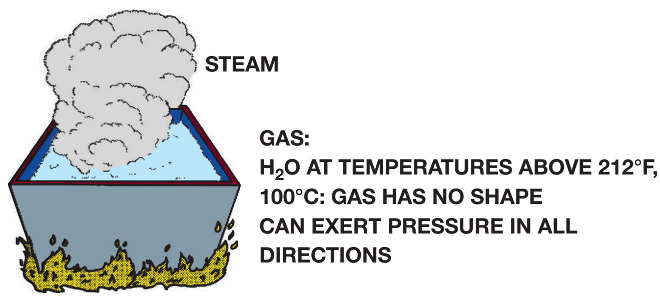


FIGURE 1–17 Adding heat to water produces steam, the gas state, with a much freer molecular action.

PURPOSE OF AN HVAC SYSTEM

CONTROL OF TEMPERATURE The goal in heating and air conditioning is to maintain a comfortable in-vehicle temperature and humidity. An air-conditioning system cools the interior of the vehicle by moving the heat from inside the vehicle to outside the vehicle. The internal body temperature of humans is about 98.6°F (37°C), which seems odd when our most comfortable temperature is 68°F to 78°F (20°C to 26°C). This means that in the summer heat must be continually given off to be comfortable, but in the winter suitable clothing is needed to maintain warmth. Body comfort is also affected by radiant heat. In the winter, the sun warms the body.

The velocity of air past our bodies is another factor in human comfort. Air movement is an important part of heating and air-conditioning systems.

CONTROL OF HUMIDITY Humid cold air feels much colder than dry air at the same temperature.

- Humid hot air slows down our natural body cooling system (evaporation of perspiration), so it can make a day feel much hotter.
- Air that is too dry also tends to make people feel uncomfortable.
- As with temperature, a range of humidity that most people feel comfortable in a relative humidly of about 45% to 55%.

As the air-conditioning system operates, it dehumidifies (removes moisture) from the air. Water vapor condenses on the cold evaporator fins just as it would on a glass holding a cold drink. This condensed water then drops off the evaporator and runs out the drain at the bottom of the evaporator case. In-vehicle humidity is reduced to about 40% to 45% on even the most humid days if the A/C is operated long enough. A good example of this dehumidification process occurs when a vehicle's A/C is operated on cold days when the windows are fogged up. It usually takes only a short time to dry the air and remove the fog from the windows. ● **SEE FIGURE 1–18.**

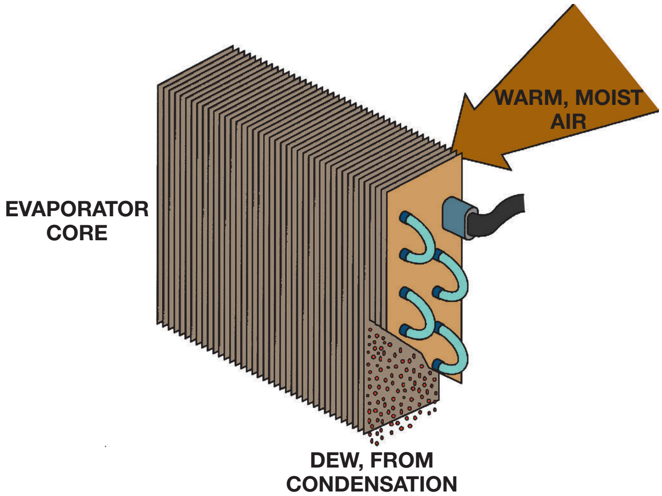


FIGURE 1–18 When air comes into contact with the cold evaporator, excess moisture forms dew. This condensed moisture leaves the car through the evaporator drain.

CLEANLINESS A side effect of air conditioning is the cleaning of the air coming into the vehicle as it passes through the cooling ductwork. The act of cooling and dehumidifying air at the A/C evaporator causes water droplets to form on the evaporator fins. Dust and other contaminants in the air that come into contact with these droplets become trapped and are flushed out of the system as the water drops drain from the evaporator. Most recent vehicles use a **cabin filter** in the A/C and heating systems to clean the air by trapping dust and pollen particles before they enter the passenger compartment.

SUMMARY

1. Heat is moved into or out of the passenger compartment to obtain a good comfort level.
2. Heat intensity is measured using the Fahrenheit or Celsius scales, and heat quantity is measured using calories and BTU.
3. The comfort zone of most humans is between 68°F and 78°F (20°C and 26°C) and 45% to 50% humidity.
4. A/C systems reduce humidity by removing moisture (water) from the air.
5. HVAC systems clean air because particles are caught by moisture on the evaporator and by filters.

REVIEW QUESTIONS

1. Is it possible for heat to be added to water without causing the temperature to increase?
2. What are the three states of matter?
3. What is the difference between heat and temperature?
4. How is relative humidity measured?
5. How does heat move?

CHAPTER QUIZ

1. The three different phases or states of matter include _____________.
   - **a.** Solid, water, and steam
   - **b.** Ice, liquid, and gas
   - **c.** Solid, liquid, and gas
   - **d.** Liquid, water, and steam
2. An air-conditioning system cools the interior of the vehicle by _____________.
   - **a.** Moving the heat from inside the vehicle to outside the vehicle
   - **b.** Blowing cold air into the interior
   - **c.** Moving heat from inside of the vehicle to the engine cooling system
   - **d.** Using the engine to move air
3. Twenty degrees Celsius is about how many degrees Fahrenheit?
   - **a.** 25
   - **b.** 45
   - **c.** 65
   - **d.** 85
4. Heat intensity is measured in _____________.
   - **a.** BTUs
   - **b.** Degrees
   - **c.** RH
   - **d.** Calories
5. A psychrometer measures _____________.
   - **a.** Temperature
   - **b.** Relative humidity
   - **c.** Amount of heat
   - **d.** Radiation
6. A BTU is a measure of _____________.
   - **a.** Temperature
   - **b.** Relative humidity
   - **c.** Amount of heat
   - **d.** Radiation
7. Heat transferred through the air is called _____________.
   - **a.** Radiation
   - **b.** Insulation
   - **c.** Convection
   - **d.** Conduction
8. Air-conditioning process works through a fluid, called a _____________ that continuously changes state from liquid to gas and back to liquid.
   - **a.** Element
   - **b.** Conductor
   - **c.** Insulator
   - **d.** Refrigerant
9. Humans prefer temperatures that are between _____________ and _____________.
   - **a.** 55°F; 65°F
   - **b.** 60°F; 70°F
   - **c.** 68°F; 78°F
   - **d.** 76°F; 86°F
10. Humans prefer relative humidity that is between _____________ and _____________.
    - **a.** 10%; 20%
    - **b.** 20%; 30%
    - **c.** 30%; 40%
    - **d.** 45%; 55%

chapter 2

THE REFRIGERATION CYCLE

LEARNING OBJECTIVES

After studying this chapter, the reader should be able to:

1. Prepare for the ASE Heating and Air Conditioning (A7) certification test content area "A" (A/C System Service, Diagnosis and Repair).
2. Explain how the A/C system works.
3. Identify the low and high side of an A/C system.
4. Explain the purpose and function of evaporators in an A/C system.
5. Explain the purpose and function of thermal expansion valves and orifice tube systems.
6. Explain the purpose and function of condensers.

KEY TERMS

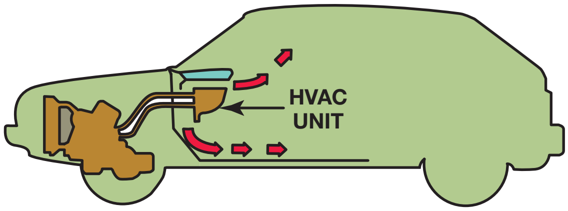


FIGURE 2–1 Air is circulated through the A/C and heating system and the vehicle to either add or remove heat.

BASIC PRINCIPLES

Automotive A/C systems operate on the principle of moving heat from inside to outside of the vehicle. Heat travels from a higher temperature (higher energy level) to a lower temperature (lower energy level).

- The flow of a refrigerant through the system is called the **refrigeration cycle** and is used to cool the interior of the vehicle.
- The heating system transfers heat from the engine's cooling system to the passenger compartment. ● **SEE FIGURE 2–1.**

REFRIGERANT MOVEMENT All automotive air-conditioning systems are closed and sealed. A refrigerant is circulated through the system by a **compressor** that is usually powered by the engine through an accessory drive belt. Older systems used CFC-12 as a refrigerant, commonly referred to as *R-12* or by its DuPont trade name of *Freon*. Starting in the early 1990s, most vehicle manufacturers now use HFC-134a (R-134a)- a refrigerant that is less harmful to the atmosphere. The basic principle of the refrigeration cycle is that as a liquid changes into a gas, heat is absorbed. The heat that is absorbed by an automotive air-conditioning system is the heat from inside the vehicle.

HOW THE A/C SYSTEM WORKS The air-conditioning (A/C) system works as follows:

1. High-pressure liquid refrigerant flows through an expansion device, which controls the amount of refrigerant that is allowed to pass through.
2. When the high-pressure liquid passes through the expansion device, the pressure drops. This causes the liquid refrigerant to evaporate in a small radiator-type unit called the **evaporator**. When the refrigerant evaporates, it absorbs heat when changing from a liquid to a gas. As the heat is absorbed by the refrigerant, the evaporator becomes cold. ● **SEE FIGURE 2–2.**

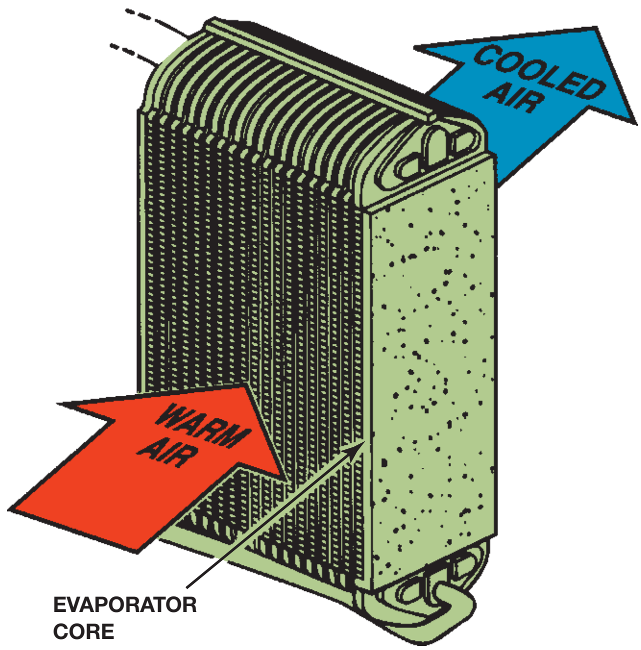


FIGURE 2–2 The evaporator removes heat from the air that enters a vehicle by transferring it to the vaporizing refrigerant.

3. After the refrigerant has evaporated into a *low-pressure gas* in the evaporator, it flows into the engine-driven compressor. The compressor compresses the low-pressure refrigerant gas into a high-temperature, high-pressure gas and forces it through the system. ● **SEE FIGURE 2–3.**
4. This high-pressure gas flows into the condenser located in front of the cooling system radiator. The **condenser** looks like another radiator, and its purpose and function is to remove heat from the high-pressure gas. In the condenser, the high-pressure gas changes (condenses) to form a high-pressure liquid as the heat from the refrigerant is released to the air. ● **SEE FIGURE 2–4.**
5. The high-pressure liquid then flows to the expansion device, which controls the amount of refrigerant that is allowed to pass through and meters the flow into the evaporator. When the high pressure of the liquid passes through the expansion device, the pressure drops and causes the refrigerant to vaporize, starting the cycle all over again.
6. Air is blown through the evaporator by the blower motor. The air is cooled as heat is removed from the air and transferred to the refrigerant in the evaporator. This cooled air is then directed inside the passenger compartment through vents.

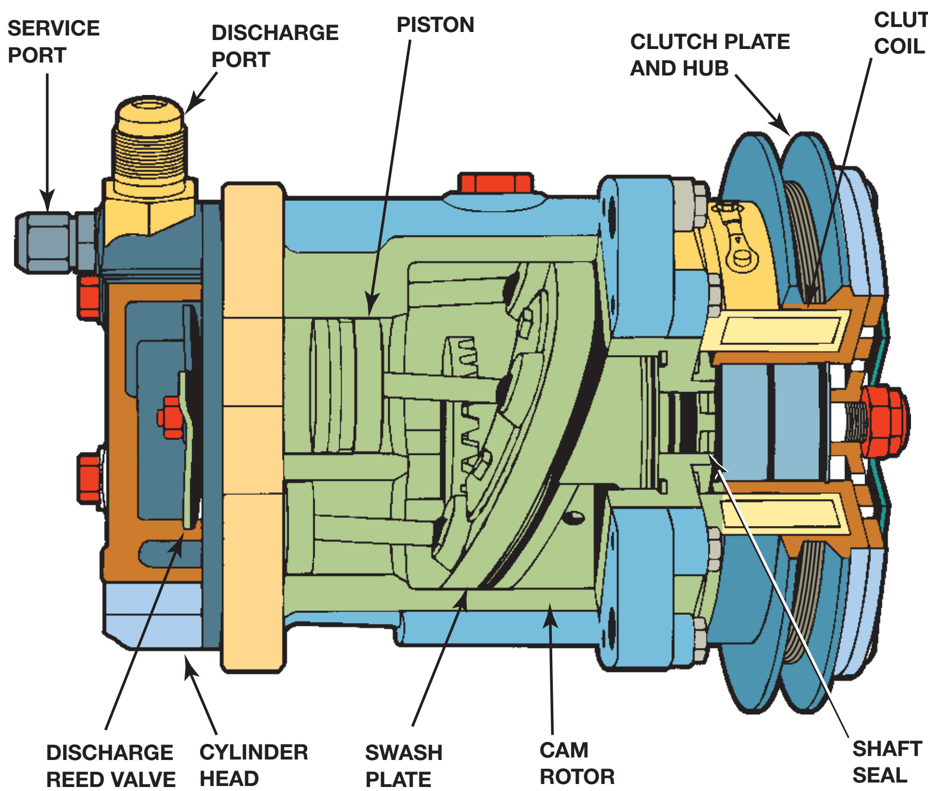


FIGURE 2–3 The compressor provides the mechanical force needed to pressurize the refrigerant.

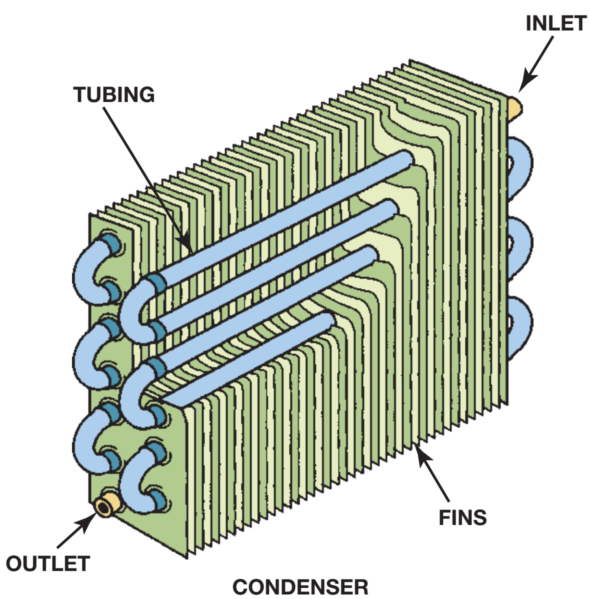


FIGURE 2–4 The condenser changes the refrigerant vapor into a liquid by transferring heat from the refrigerant to the air stream that flows between the condenser fins.

HIGH- AND LOW-SIDE IDENTIFICATION

A/C systems can be divided into two parts:

1. **Low side**—it has low pressure and temperature. The low side begins at the expansion device and ends at the compressor. The refrigerant boils or evaporates in the low side.

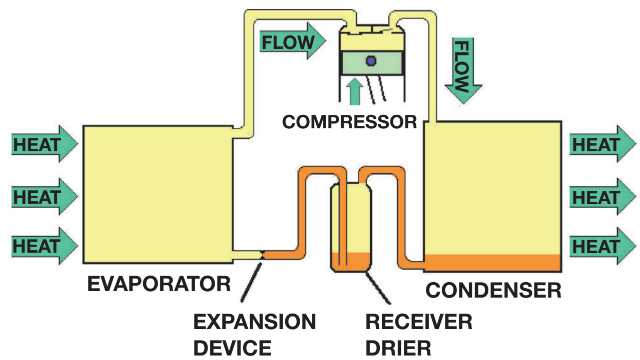


FIGURE 2–5 Refrigerant changes state to a vapor as it absorbs heat in the low side and into a liquid as it loses heat in the high side.

2. **High side**—it has higher pressures and temperatures. The high side begins at the compressor and ends at the expansion device. The refrigerant condenses in the high side. The high side line is often called the **liquid line**. ● **SEE FIGURE 2–5.**

In an operating system, the low and high sides can be identified by:

- **Pressure**—A pressure gauge shows low pressure in the low side and high pressure in the high side.

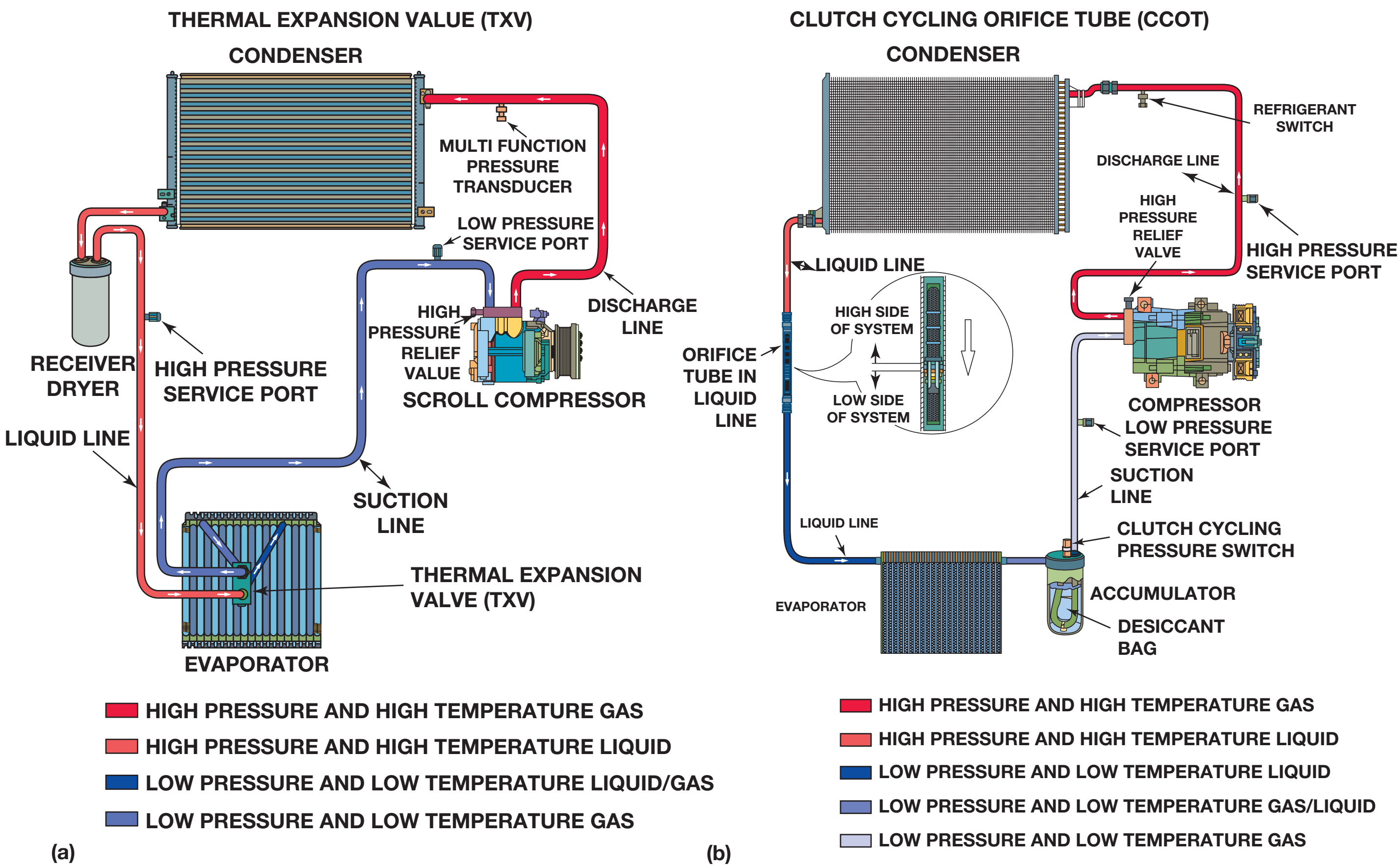


FIGURE 2–6 Automotive A/C systems are either a TXV system with a receiver–drier (a) or an OT system with an accumulator. (b) Various compressors are used with both systems.

? FREQUENTLY ASKED QUESTION

How Does the Inside of the Vehicle Get Cooled?

The underlying principle involved in air conditioning or refrigeration is that "cold attracts heat." Therefore, a cool evaporator attracts the hot air inside the vehicle. Heat always travels toward cold and when the hot air passes through the cold evaporator, the heat is absorbed by the cold evaporator, which lowers the temperature of the air. The cooled air is then forced into the passenger compartment by the blower through the air-conditioning vents.

- **Sight**—On high-humidity days, the cold low-side tubing often collects water droplets and may even frost.
- **Temperature**—The low side is cool to cold, and the high side is hot.
- **Tubing size**—Low-side tubes and hoses are larger (vapor), and high-side tubes and hoses are smaller (liquid).

TYPES OF EXPANSION DEVICES Automotive A/C systems are of two types:

- **Orifice tube (OT)** systems—Orifice tube systems are also called *cycling clutch orifice tube (CCOT)* and *fixed orifice tube (FOT)* systems.
- **Thermal expansion valve (TXV)** systems. TXV systems are now being used by most vehicle manufacturers mainly due to the reduction in the amount of refrigerant required in this type of system. ● **SEE FIGURE 2–6.**

LOW-SIDE OPERATION The low side begins at the refrigerant expansion or flow metering device, either a TXV or an OT, which produces a pressure drop. The low side ends at the compressor, which increases the pressure. When the A/C system is in full operation, the goal of most systems is to maintain an evaporator temperature just above the freezing point of water, 32°F (0°C). This temperature produces the greatest heat exchange without ice formation on the evaporator fins (evaporator icing reduces the heat transfer). ● **SEE FIGURE 2–7.**

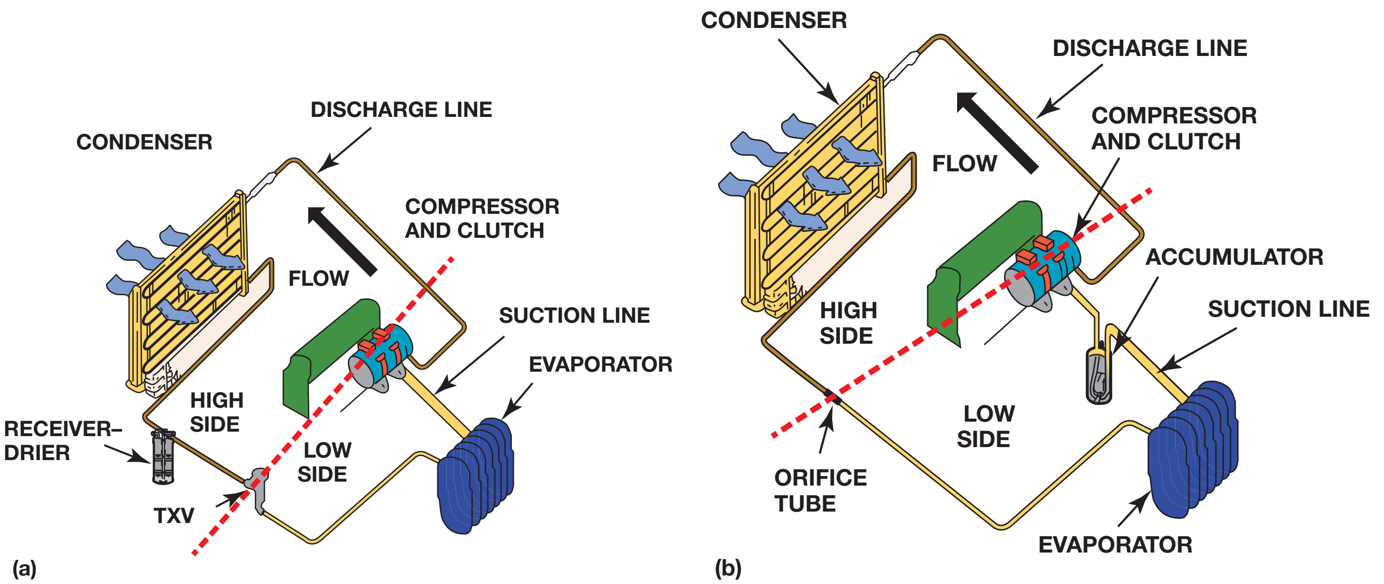


FIGURE 2–7 (a) The low side begins at the TXV or OT and includes the evaporator and suction line to the compressor. (b) The OT system includes an accumulator. The area above the red line represents high pressure and high temperature. The area below the red line represents lower temperature and lower pressures.

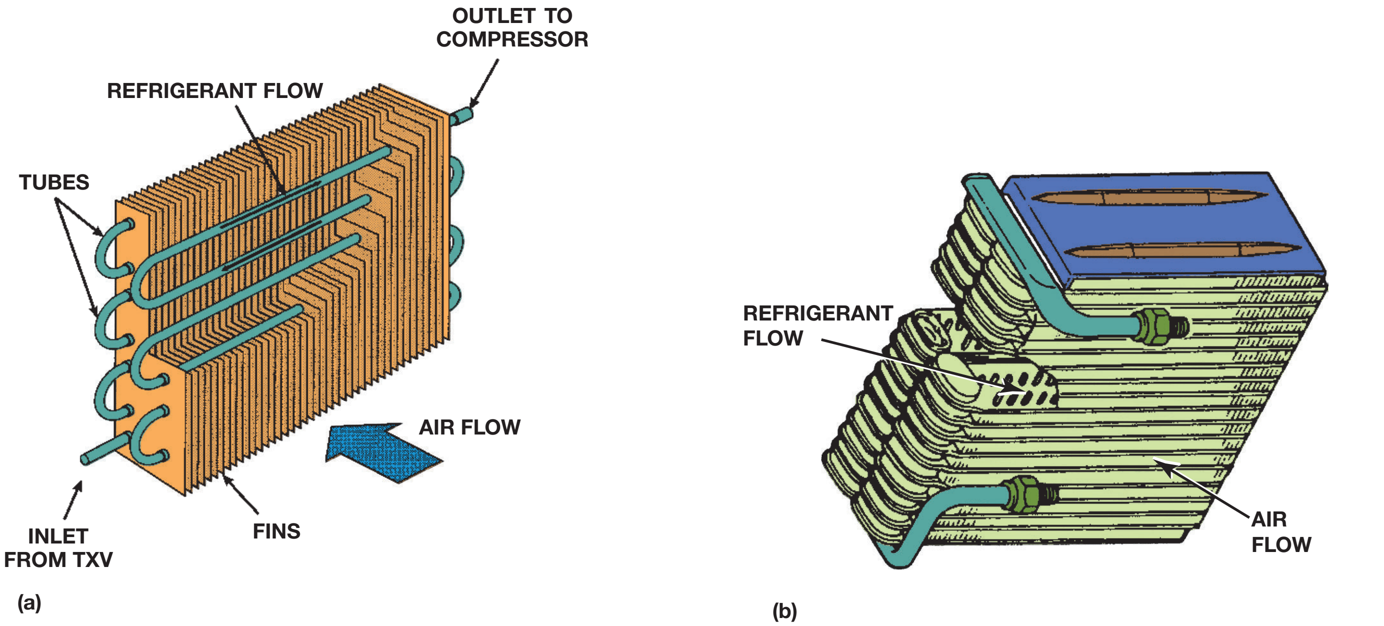


FIGURE 2–8 (a) A tube-and-fin and (b) a plate evaporator. Each type has a large contact area for heat to leave the air and enter the refrigerant.

EVAPORATORS

PURPOSE AND FUNCTION The evaporator is the heat exchanger and absorbs heat from the passenger compartment. The refrigerant enters the evaporator as a liquid spray or mist, leaving an area of a few hundred pounds per square inch (PSI) and passing through a small orifice into an area of about 30 PSI. Like most heat exchangers, a well-designed evaporator has a large amount of surface area in contact with the refrigerant and the air from the passenger compartment. The heat from the air causes the refrigerant to boil and turn into vapor and the cooler air is returned to the passenger compartment. ● **SEE FIGURE 2–8.**

The cold temperature in the evaporator is produced by boiling the refrigerant. Refrigerants have very low boiling points, well below 0°F (–18°C); when the liquid boils, it absorbs a large amount of heat, called the *latent heat of vaporization*. To produce cooling, liquid refrigerant must enter and boil inside the evaporator. The amount of heat an evaporator absorbs is

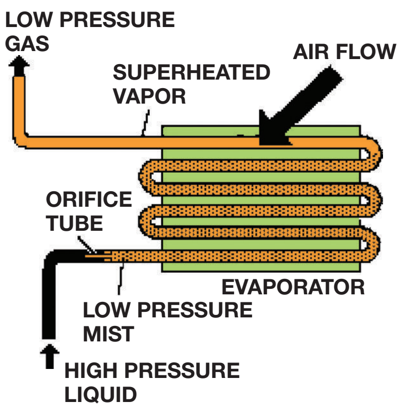


FIGURE 2–9 As liquid refrigerant enters the evaporator, the boiling point will try to drop to as low as 32°F (0°C) because of the drop in pressure. The cold temperature causes the refrigerant to absorb heat from the air circulated through the evaporator.

directly related to the amount of liquid refrigerant that boils inside it. ● **SEE FIGURE 2–9.**

A properly operating evaporator has a temperature just above 32°F (0°C), and refrigerant pressure is directly related to temperature. R-134a has a 27-PSI (186-kPa) pressure at 32°F (0°C). Abnormal temperatures and pressures indicate that something is wrong, such as the evaporator might have too much or too little refrigerant.

- **Starved evaporator**—An evaporator that has a low pressure but a temperature that is too warm is called "starved," which means that not enough refrigerant is entering to produce the desired cooling effect. A starved evaporator is usually the result of a restriction at or before the expansion device or an undercharge of refrigerant.
- **Flooded evaporator**—If more refrigerant enters the evaporator than can boil, the evaporator floods. In this case the pressure is higher than normal. A flooded evaporator is usually the result of having too much refrigerant in the system. ● **SEE FIGURE 2–10.**

THERMAL EXPANSION VALVES

TERMINOLOGY A thermal expansion valve (TXV) is a variable valve that changes the size of the valve opening in response to the cooling load of the evaporator. A TXV is controlled by evaporator temperature and pressure so

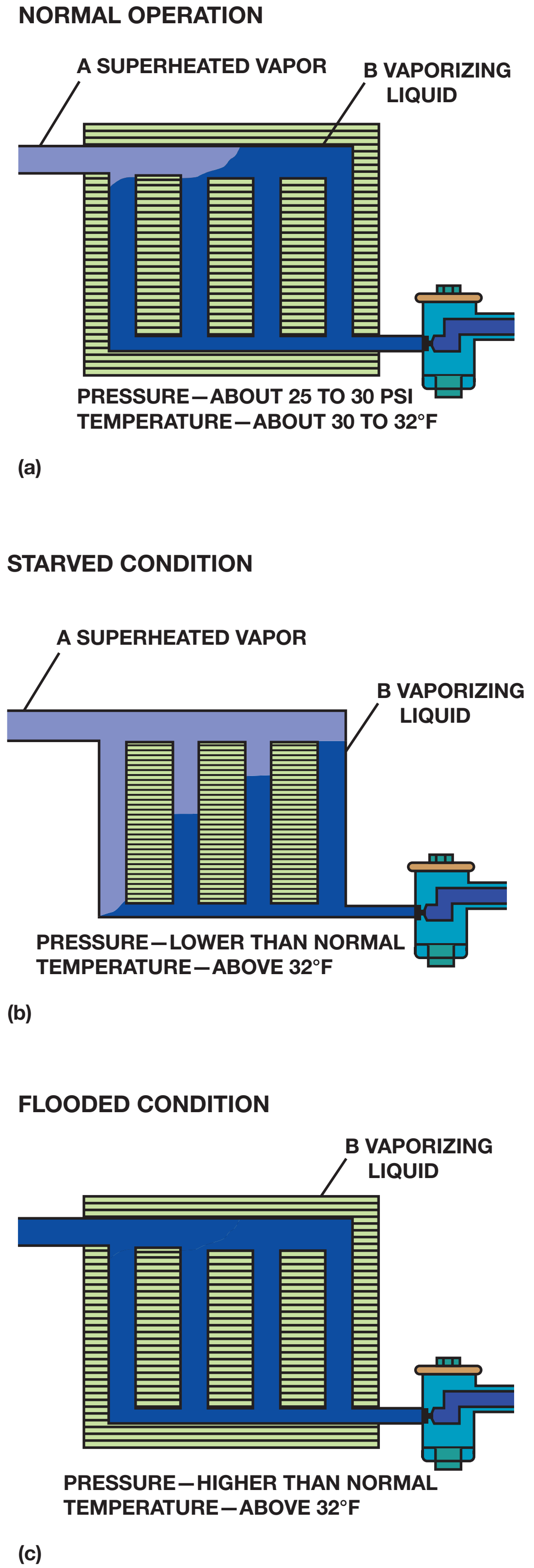


FIGURE 2–10 (a) If proper amount of refrigerant enters the evaporator, it has a slight superheat as it leaves. (b) A starved condition, in which not enough refrigerant enters the evaporator, does not produce as much cooling. (c) If too much refrigerant enters, the evaporator floods because the refrigerant will not boil.

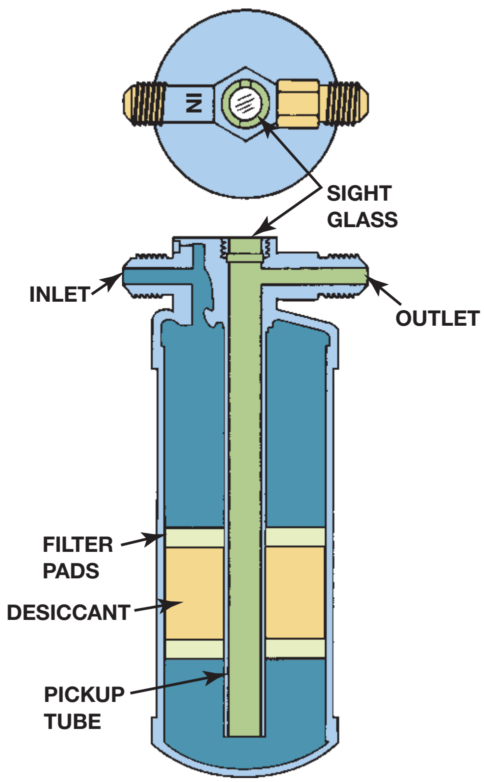


FIGURE 2–11 Expansion-valve systems store excess refrigerant in a receiver–drier, which is located in the high-side liquid section of the system.

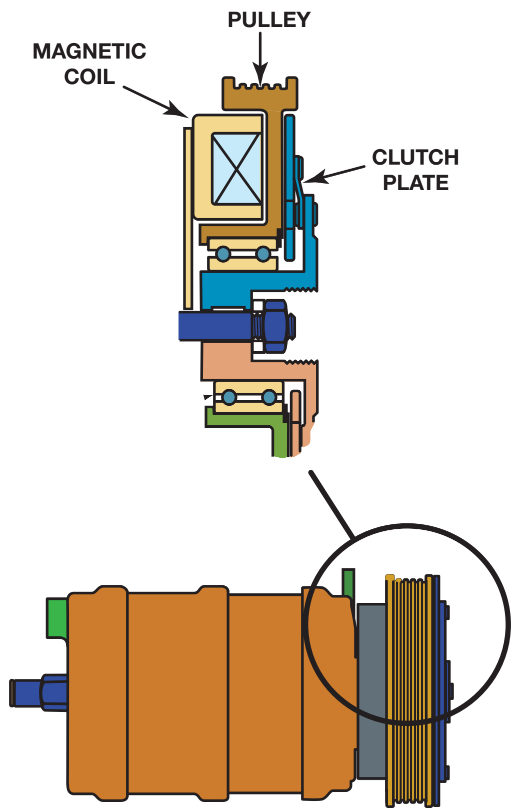


FIGURE 2–12 The compressor clutch allows the compressor to cycle off and on to control evaporator temperature and to shut the system off.

that it opens to flow as much refrigerant as possible when a lot of cooling is needed and all of the refrigerant must boil in the evaporator. Most TXVs are calibrated so that the outlet temperature is a few degrees above the inlet pressure and temperature. When there is a lower cooling load, the TXV must reduce the flow.

RECEIVER–DRIER A **receiver–drier** is used in the high side of a TXV system. It contains a desiccant to remove moisture and provides a storage chamber for liquid refrigerant. Most receiver–driers also contain a filter to trap debris that might plug the TXV.

NOTE: Older receiver–driers have a sight glass in the outlet line so the refrigerant flow can be checked to see if it is all liquid or contains bubbles. A receiver–drier should be about half full of liquid, so vapor bubbles are an indication of an undercharge. A sight glass is not used in most R-134a systems because the refrigerant has a cloudy appearance in a properly charged system.
● **SEE FIGURE 2–11.**

ORIFICE TUBE SYSTEMS

PURPOSE AND FUNCTION An orifice tube is a restriction in the liquid line that forces the refrigerant to expand as it passes through the small opening (orifice). When the refrigerant expands, the temperature of the refrigerant drops and starts to evaporate in the evaporator. There are two basic designs of orifice tube system, including:

1. A cycling clutch (CC) system that disengages the compressor and shuts the system off when the evaporator temperature or pressure drops below freezing point. Most A/C compressors are driven by a belt from the engine through an electromagnetic clutch. ● **SEE FIGURE 2–12.**
2. A variable displacement compressor that is used to control evaporator pressure and temperature by controlling the amount of refrigerant passing through the orifice tube.

? FREQUENTLY ASKED QUESTION

What is the Difference Between a Receiver–Drier and an Accumulator?

A receiver–drier is used with a thermal expansion valve (TXV) system and is located in the high-pressure (liquid) side of the system between the condenser and the expansion valve. An accumulator is used in the orifice tube system and is located in the low side of the system between the evaporator and the compressor. The accumulator is needed in an orifice tube system because it prevents any liquid refrigerant from entering the compressor, which would destroy the compressor. It traps and holds any liquid refrigerant that leaves the evaporator. Both assemblies contain a desiccant to remove any moisture that may be in the system to help prevent possible acid formation, which can decrease component life. ● **SEE FIGURE 2–13.**

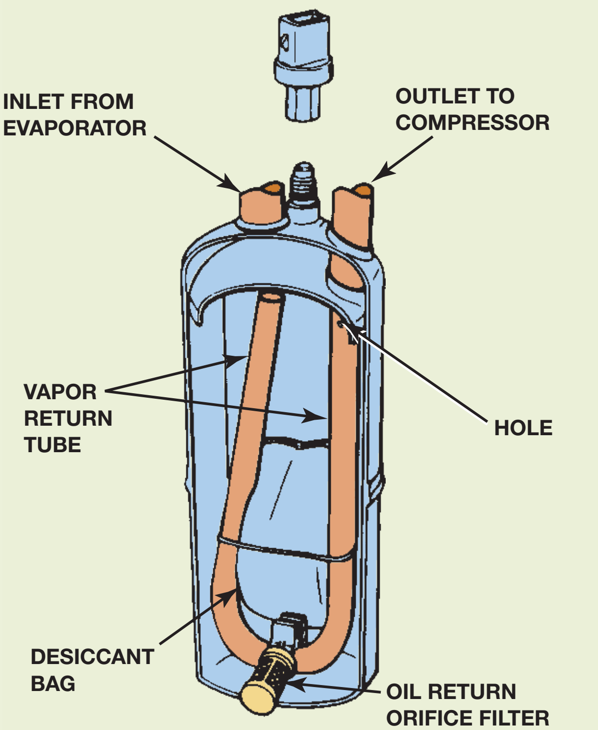


FIGURE 2–13 Expansion-valve systems store excess refrigerant in a receiver–drier, which is located in the high-side liquid section of the system, whereas orifice tube systems store excess refrigerant in an accumulator (shown here) located in the low-side vapor section of the system.

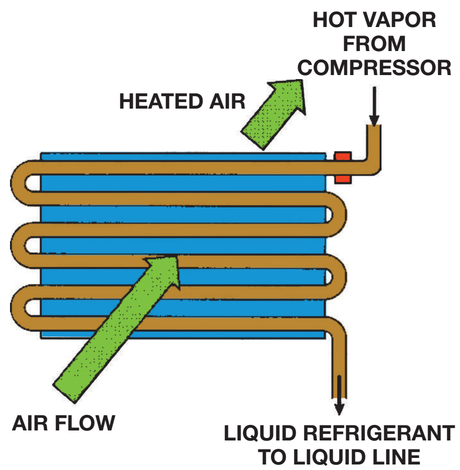


FIGURE 2–14 A condenser is a heat exchanger that transfers heat from the refrigerant to the air flowing through it.

? FREQUENTLY ASKED QUESTION

What Is Sub-Cooling?

The term **sub-cooling** refers to a liquid existing at a temperature below its normal condensation temperature. The condenser removes heat and changes a high-pressure vapor into a high-pressure liquid. As the superheated (high-pressure) gas is pushed into the condenser, the temperature is reduced. The refrigerant does not start to change state until the temperature reaches what is called its *saturated pressure-temperature*. At saturation pressure-temperature point, the change of state becomes latent heat (invisible or hidden heat). The temperatures of the liquid and the vapor will stay the same until the temperature of the refrigerant starts to drop. Temperature of the refrigerant will start to drop once 98% to 99% of the refrigerant becomes liquid.

CONDENSERS

PURPOSE AND FUNCTION The condenser, like the evaporator, is a heat exchanger. Low-pressure refrigerant vapor is compressed by the compressor into a high-temperature, high-pressure vapor. This vapor then passes into the condenser where air passing over the condenser cools the refrigerant and causes it to condense into a high-temperature liquid. The refrigerant enters the top of the condenser as a hot vapor and leaves from the bottom as a cooler liquid. ● **SEE FIGURE 2–14.**

REFRIGERANT CHARGE LEVEL

PRINCIPLES For an A/C system to work properly, there should be a constant flow of liquid refrigerant through the TXV or OT. While operating, the following occurs:

- The evaporator contains a refrigerant mist in the first two-thirds to three-fourths of its volume, with vapor in the remaining portion.
- The condenser contains a condensing vapor in the upper portion, with liquid in the bottom passages.
- The line connecting the condenser to the expansion device is filled with liquid.
- The accumulator is about half full of liquid so that liquid refrigerant does not enter the compressor.

Most recent A/C systems have improved efficiency and reduced the size of some components so they can operate with smaller charge volumes. At one time, the refrigerant capacity of many domestic systems was in the 3-lb. to 4-lb. (1.4 kg to 1.8 kg) range. However, recently most systems hold 1.0 lb. to 2.5 lb. (0.5 kg to 1.1 kg) of refrigerant. Some of the new systems, such as the Toyota Yaris, have a capacity of less than a pound (0.43 kg). With this reduced volume, an accurate charge amount is more critical.

- **Undercharge**—If the volume of liquid drops so that vapor bubbles pass through the TXV or OT, the system is **undercharged** and its cooling effectiveness is reduced.
- **Overcharge**—If an excessive amount of refrigerant is put into a system then the excess volume partially fills the condenser as a liquid and reduces its effective volume. This is called an **overcharge** and causes abnormally high pressures, especially in the high side, and poor cooling at the evaporator. ● **SEE FIGURE 2–15.**

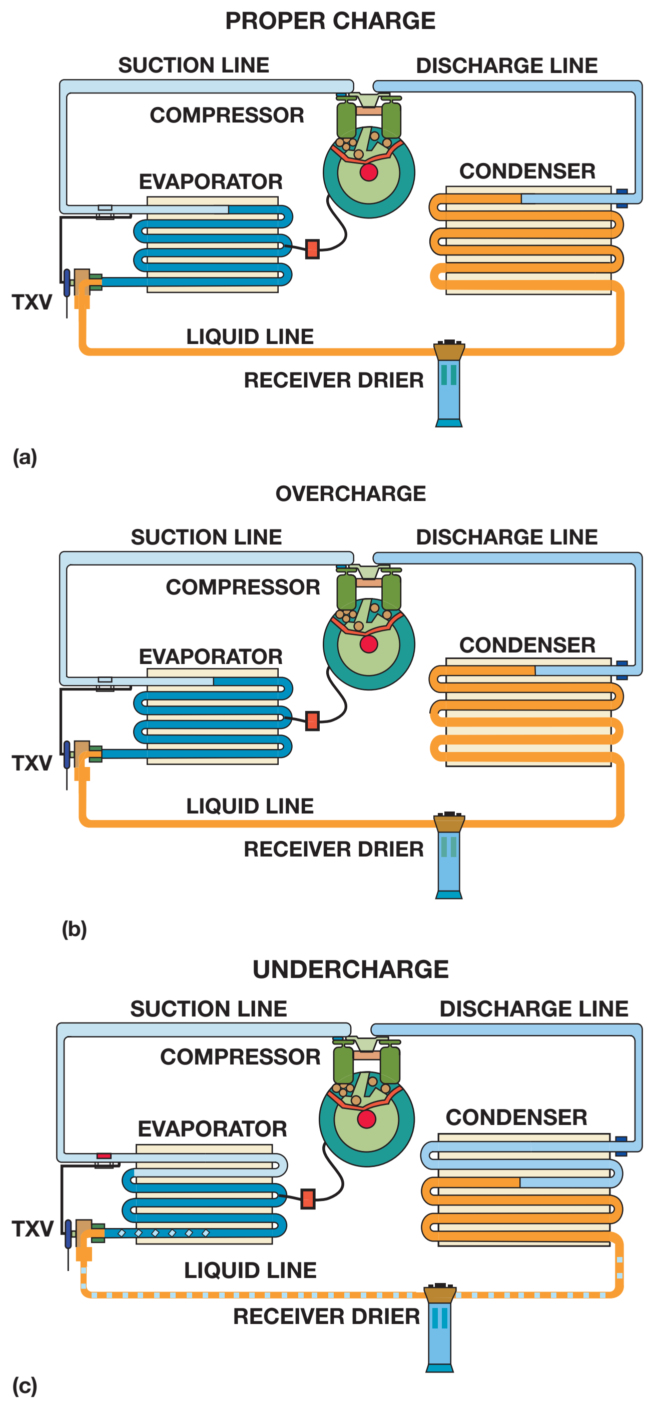


FIGURE 2–15 (a) A properly charged system has the condenser filled with condensing vapor and some liquid, a liquid line filled with liquid, a receiver–drier about half full of liquid, and an evaporator with vaporizing liquid. (b) An overcharge with too much liquid causes liquid to partially fill the condenser. (c) An undercharge has vapor in the liquid line and a starved evaporator.

EVAPORATOR ICING CONTROLS

PURPOSE AND FUNCTION Most A/C systems operate at maximum capacity when it is necessary to cool the vehicle. Compressor size (displacement) and the sizes of the evaporator and condenser determine cooling power and are designed to cool the vehicle and its passengers on a hot day. Vehicle size and glass area, compressor displacement and operating speed, number of passengers, ambient temperature, and vehicle speed are all design parameters that are considered during the initial design of the A/C and heating systems. Some

? FREQUENTLY ASKED QUESTION

What Is "Superheat"?

Superheat is the amount of heat added to the refrigerant after it has changed from liquid to vapor. Superheat is usually measured as the actual temperature difference between the boiling point of the refrigerant at the inlet and at the outlet of the evaporator. Typical values for superheat in an evaporator are between 4°F and 16°F (3°C and 10°C). Superheat is important because it ensures that all (or almost all) of the refrigerant vaporizes before leaving the evaporator.

systems are designed to cool a vehicle with the engine at idle speed and the compressor running at its slowest speed. Newer systems are made as small as practical to reduce HVAC system size and vehicle weight for improved fuel economy.

As the vehicle cools down, the cooling load on the evaporator drops, and its temperature also drops. As mentioned earlier, the minimum temperature for an evaporator is 32°F, the point at which water freezes and ice and frost form. There are several ways of preventing evaporator icing, including the following:

- Cycling the compressor clutch
- Controlling evaporator pressure so it does not drop below 30 PSI
- Reducing the displacement of the compressor by using a variable displacement compressor.

Early A/C systems used a temperature-controlled switch mounted in the airstream from the evaporator. This thermal switch, also called an *icing switch* or *defrost switch*, was set to open and stop the current flow to the clutch when the temperature drops below 32°F (0°C) and reclose when there is a temperature increase of about 10 Fahrenheit degrees (6 Celsius degrees). This causes a pressure increase of about 10 PSI to 20 PSI that, in turn, produces sufficient temperature rise to melt any frost or ice on the fins.

THERMISTOR Some newer systems use a **thermistor**, which is a solid-state device that changes its electrical resistance in inverse relationship to its temperature. When the temperature increases, the resistance of the thermistor decreases. It is used as an input to an electronic control module (ECM) to provide the actual evaporator temperature control.

PRESSURE SWITCHES Many orifice tube systems use a two-wire **pressure switch** mounted in the accumulator or the **suction line** to the compressor. The evaporator temperature and pressure are closely linked and they drop together. As the *cutout pressure switch* senses the pressure dropping below a certain point (about 30 PSI), it opens to stop the compressor. The pressure switch recloses when the pressure increases, with the *cut-in pressure* being about 42 PSI to 49 PSI, depending on the vehicle. With either of these systems, if ice and frost start to form because the evaporator gets too cold, the ice and frost melt during the off part of the cycle. ● **SEE FIGURE 2–16.**

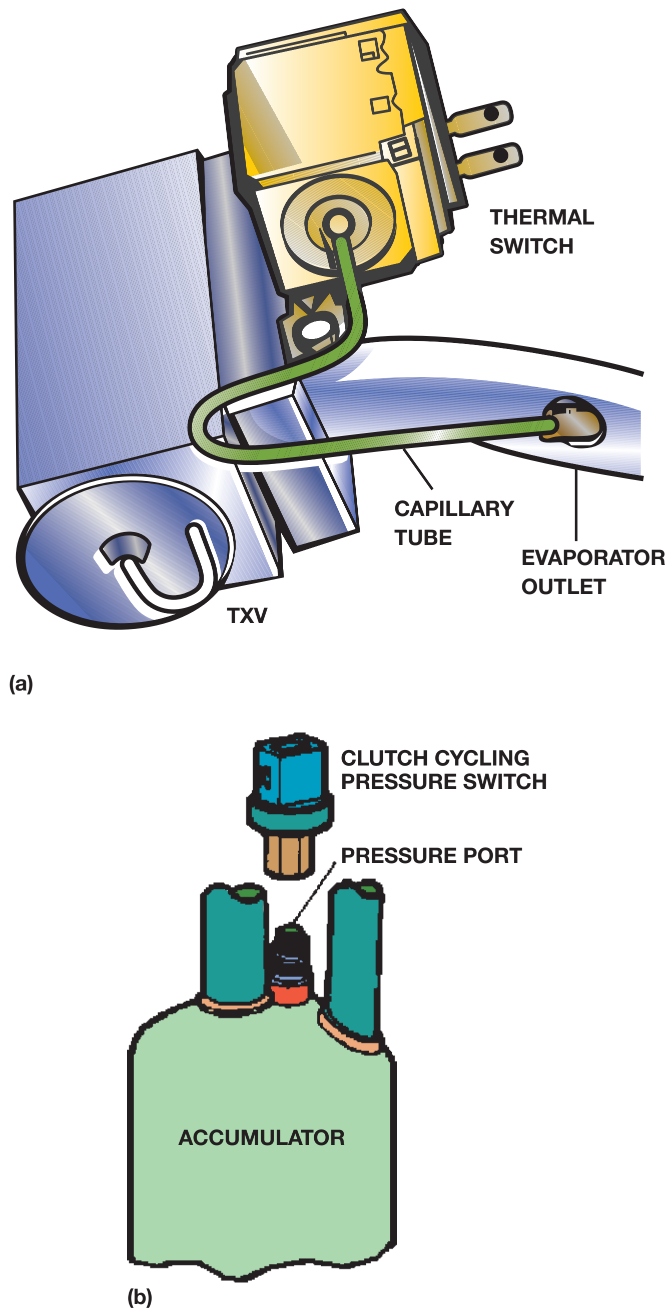


FIGURE 2–16 (a) Most TXV systems use a thermal switch to cycle the compressor out when the evaporator gets too cold. (b) Most orifice tube systems use a pressure switch to cycle the compressor out when the low-side pressure drops too low.

Most recent vehicles use a **pressure sensor** in place of a pressure switch. The resistance of the sensor changes in direct relation to the pressure. It is an input to a PCM/ECM used for compressor clutch, cooling fan, and idle-speed control as well as low-pressure and high-pressure protection. ● **SEE FIGURE 2–17.**

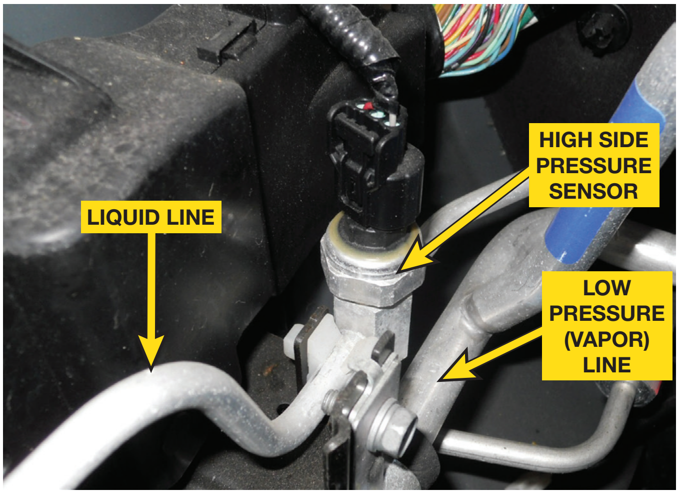


FIGURE 2–17 A typical three-wire pressure sensor used on the high side (vapor) line. The three wires are the voltage supply (usually 5 volts), ground, and signal wire.

SUMMARY

1. Automotive A/C systems operate on the principle of moving heat from inside to outside of the vehicle.
2. All automotive air-conditioning systems are closed and sealed. A refrigerant is circulated through the system by a compressor that is usually powered by the engine through an accessory drive belt.
3. The liquid refrigerant evaporates in a small radiator-type unit called the evaporator.
4. After the refrigerant has evaporated into a low-pressure gas in the evaporator, the refrigerant flows into the engine-driven compressor.
5. From the compressor, high-pressure gas flows into the condenser located in front of the cooling system radiator.
6. Automotive A/C systems are either orifice tube (OT) systems or thermal expansion valve (TXV) systems.
7. A receiver–drier is used with a TXV system and is located in the high pressure (liquid) side of the system.
8. An accumulator is used in an orifice tube system and is located in the low side of the system between the evaporator and the compressor.

REVIEW QUESTIONS

1. How does the air conditioning cool the inside of the vehicle?
2. What are the major components of the refrigeration cycle?
3. How does the refrigeration system work?
4. What is the difference between a pressure switch and a pressure sensor?

CHAPTER QUIZ

1. Heat travels from ______________.
   a. Hot to cooler
   b. Cold to warmer
   c. Either from hot to cool or the other way depending on the weather
   d. From outside the vehicle to inside the vehicle
2. The refrigerant is circulated through the system by a ______________.
   a. Condenser
   b. Evaporator
   c. Compressor
   d. Thermal expansion valve or orifice tube

3. When the refrigerant evaporates, it absorbs heat when it changes from liquid to gas. In which unit does this occur?
   a. Condenser
   b. Evaporator
   c. Compressor
   d. Thermal expansion valve or orifice tube
4. Which unit contains a desiccant to remove moisture from the system?
   a. Receiver–drier
   b. Accumulator
   c. Evaporator
   d. Both a and b
5. The low side of the refrigeration cycle means __________.
   a. It has low pressure and temperature
   b. It begins at the compressor and ends at the expansion device
   c. That the refrigerant condenses
   d. It is called the liquid line
6. The high side of the refrigeration cycle means it ________.
   a. Has low pressure and temperature
   b. Begins at the expansion device and ends at the compressor
   c. Has higher pressures and temperatures
   d. The refrigerant boils or evaporates
7. A ____________ is a variable valve that changes the size of the valve opening in response to the cooling load of the evaporator.
   a. Orifice tube
   b. Compressor
   c. Thermal expansion valve (TXV)
   d. Receiver–drier
8. Pressures are controlled in an orifice tube (OT) system by ____________.
   a. Using a variable valve
   b. Cycling an electromagnetic compressor clutch on and off as needed
   c. Using a variable displacement compressor
   d. Either b or c
9. Which condition can cause the air-conditioning system to produce less-than normal cooling?
   a. Overcharged with refrigerant
   b. Undercharged with refrigerant
   c. Either under- or overcharged
   d. Superheat condition
10. The condenser ____________.
   a. Is a heat exchanger
   b. Is a device where air passing over it cools the refrigerant and causes it to change into a high-temperature liquid
   c. Transfers heat from the refrigerant to the air flowing
   d. All of the above

chapter 3

AIR-CONDITIONING COMPRESSORS AND SERVICE

LEARNING OBJECTIVES

After studying this chapter, the reader should be able to:

1. Prepare for ASE Heating and Air Conditioning (A7) certification test content area “B” (Refrigeration System Component Diagnosis and Repair).
2. State the different types of A/C compressors.
3. Discuss the parts and operation of compressor clutches.
4. Discuss compressor valves and switches.
5. Explain A/C compressor diagnosis and service.

KEY TERMS

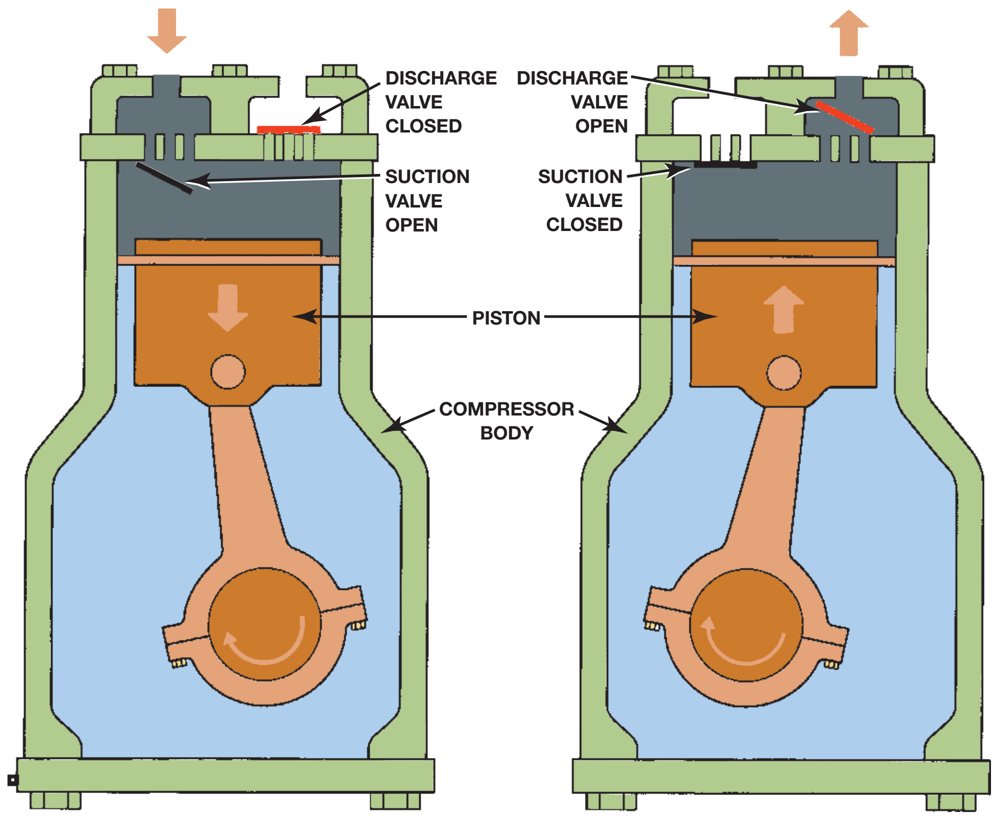


FIGURE 3–1 In a piston compressor, when moving downward, the piston creates a drop in pressure inside the cylinder. The resulting difference in pressure allows the suction valve to open. Refrigerant then flows into the cylinder. When the piston moves upward on discharge stroke, the pressure closes the intake valve and forces the refrigerant out the discharge valve.

COMPRESSORS

PURPOSE AND FUNCTION The air-conditioning compressor can be thought of as a pump that circulates refrigerant. It has to work against the restriction of the thermal expansion valve (TXV) or orifice tube (OT). The pressure must be increased to the point where refrigerant temperature is above ambient air temperature and there is enough heat transfer at the condenser to get rid of all the heat absorbed in the evaporator. Most A/C compressors are driven by a belt and pulley from the engine.

TYPES OF A/C COMPRESSORS There are many types of A/C compressors used on vehicles, including the following:

- **Piston compressors**—Most older automotive compressors used a crankshaft, similar to a small gasoline engine, and a reciprocating-piston type. Newer piston compressors use a swash or wobble plate.
- **Vane compressors**—Vane compressor has vanes that contact the rotor housing at each end, and they slide to make a seal at each end as the rotor turns.
- **Scroll compressors**—Scroll compressors require rather complex machining to achieve constant sealing between the fixed and movable scrolls.

PISTON COMPRESSORS

PISTON COMPRESSOR OPERATION A piston compressor moves the pistons up and down in a cylinder to produce pumping action and controls the refrigerant flow with two sets of **reed valves**.

- The downward or **suction stroke** of the piston causes the refrigerant to flow from the compressor suction cavity to push the suction reed open and fill the cylinder. The suction cavity is connected to the evaporator so it contains refrigerant vapor at evaporator pressure.
- An upward stroke, or **discharge stroke**, of the piston generates pressure to force the refrigerant through the discharge reed into the discharge chamber and on to the condenser. The discharge pressure becomes high-side pressure. ● **SEE FIGURE 3–1.**

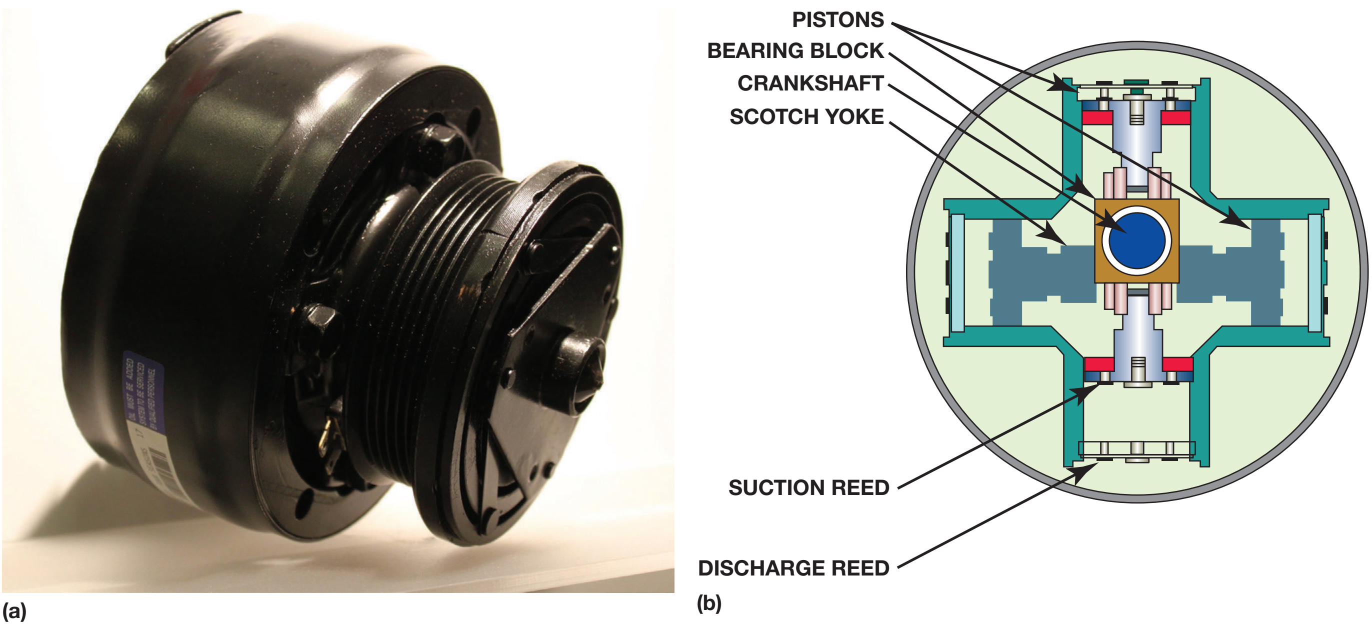


FIGURE 3–2 (a) An R-4 compressor. (b) This unit has two pairs of pistons that are driven by a Scotch yoke.

Piston compressors have some disadvantages; chief among them is the high inertial loads that result from moving a piston at a rather high speed, bringing it to a stop, moving it at a high speed in the opposite direction, bringing it to a stop, and so on. This movement produces vibrations and severe stress on moving parts.

RADIAL-TYPE PISTON COMPRESSORS These compressors use two double pistons that are mounted over a bearing block. The crankshaft moves the bearing block in a circular orbit that moves the pistons through their strokes. The GM R-4 compressor is the most common. ● **SEE FIGURE 3–2.**

COAXIAL SWASH-PLATE COMPRESSORS Coaxial swash-plate compressors drive the pistons through a swash plate, which is attached to the driveshaft. The swash plate is mounted at an angle so it will wobble and cause the reciprocating action of the pistons.

- The swash plate revolves with the shaft with each piston having a pair of bearings that can pivot as the swash plate slides through them.
- The pistons are double ended so that each end can pump, and the pistons are arranged parallel to and around the driveshaft. This is called a *coaxial* arrangement.
- One driveshaft revolution causes each piston end to move through a complete pumping cycle. The most common arrangement is three double pistons making a 6-cylinder compressor and a 10-cylinder using five pistons. ● **SEE FIGURE 3–3.**

A swash-plate compressor must have passages to transfer refrigerant between the suction and discharge chambers at each end of the compressor. The suction crossover passage is usually designed so that it can provide lubrication to internal moving parts.

General Motors uses the following compressor designations:

- Delco Air: DA
- Harrison: H
- Harrison Radiator: HA
- Harrison Redesigned: HR
- High Efficiency: HE
- Truck: HT
- Upgraded HT: HU

Nippondenso also manufactures 6-cylinder and 10-cylinder coaxial compressors. This design is used as OEM equipment by the Chrysler Corporation, the Ford Motor Company, and other vehicle manufacturers around the world. Denso coaxial compressors, like those of other manufacturers, use a four-part aluminum body with two cylinder assemblies, rear head, and front head sealed by O-rings. Either a single-key drive or a splined drive is used between the clutch drive plate and the compressor shaft.

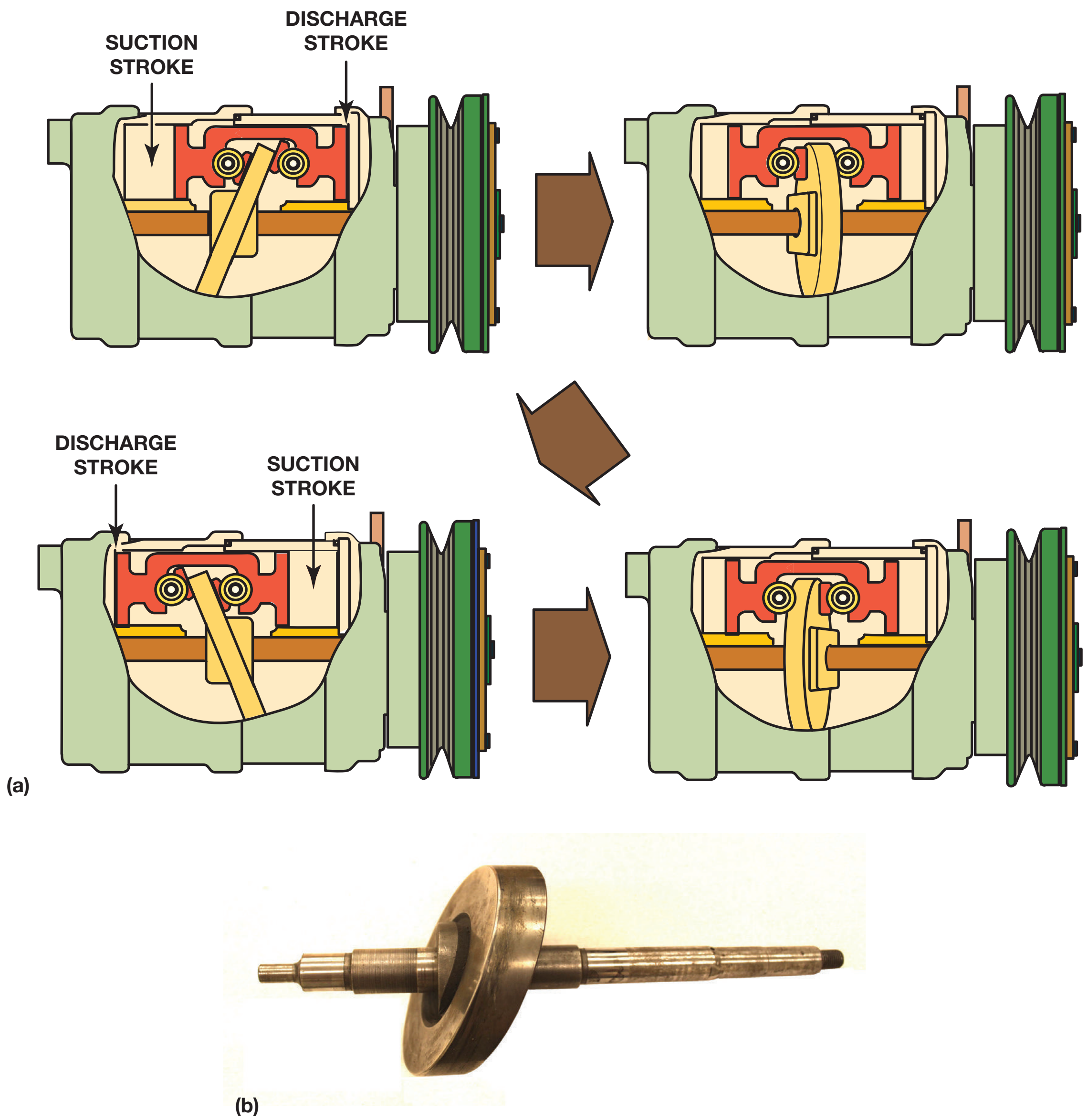


FIGURE 3–3 (a) One of the double pistons of a swash-plate compressor as it move through a pumping cycle. (b) A compressor shaft with the swash plate.

Several other Japanese manufacturers have produced 6-cylinder and 10-cylinder swash-plate compressors. These manufacturers include:

- Calsonic
- Hitachi
- Mitsubishi
- Nihon Radiator
- Seltec
- Zexel (formerly Diesel Kiki)

COAXIAL WOBBLE-PLATE COMPRESSORS Wobble-plate compressors drive the pistons through an angle plate that looks somewhat like a swash plate, but the wobble plate does not rotate and drives single pistons through piston rods. Wobble-plate compressors commonly use five or seven cylinders. ● **SEE FIGURE 3–4.**

VARIABLE DISPLACEMENT WOBBLE-PLATE COMPRESSORS A variable displacement compressor provides smooth operation with no clutch cycling, a constant 32°F (0°C) evaporator, and the most efficiency. Changing the compressor displacement is the major control for preventing evaporator icing.

- This design includes a large compressor that can pump enough refrigerant to meet high cooling loads, and it

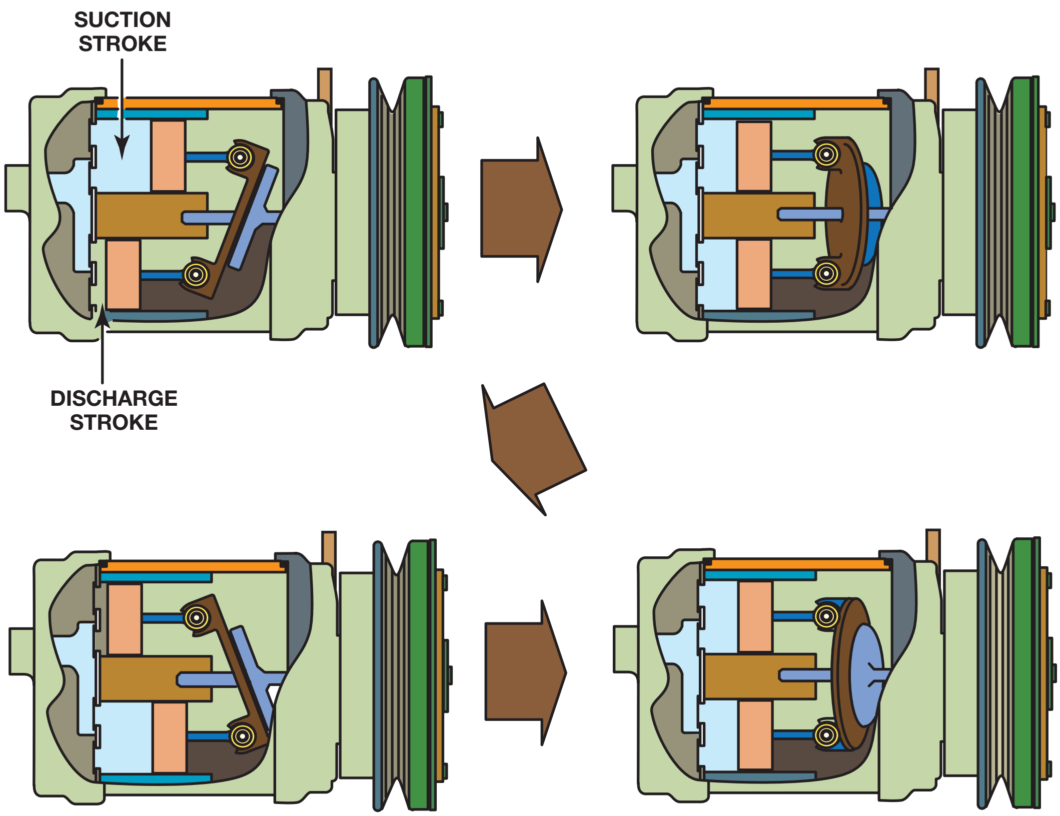


FIGURE 3–4 Two of the pistons of a wobble-plate compressor as they move through a pumping cycle.

reduces the displacement and pumping capacity of the compressor to match the needs of the evaporator as the evaporator cools.

- When there is a low cooling load at the evaporator, the wobble plate is moved to a less angled position. Some designs can reduce wobble-plate angle to 1% or 2% of the maximum stroke angle. This feature makes the compressor more efficient by reducing the drive load when it is not needed and also eliminates the need to cycle the compressor off and on. ● **SEE FIGURE 3–5.**

Wobble-plate angle is determined by the relative pressure at each end of the piston, and the angle is controlled by changing the pressure in the crankcase.

- When the cooling load calls for high output and maximum displacement, crankcase pressure is kept low, and the wobble plate is at its maximum angle. The control valve bleeds crankcase pressure into the compressor suction cavity to lower the pressure.
- When cooling demand lessens, the control valve closes the bleed to the suction cavity and opens a passage between the discharge cavity and the crankcase, raising the pressure. Increasing crankcase pressure raises the pressure on the bottom side of the pistons and causes the wobble plate to move to a low angle, reducing displacement. A typical variable compressor has a displacement of 0.6 cu. inch to 9.2 cu. inch (10 cc to 151 cc). When maximum cooling is needed, the displacement is 9.2 cu. inch, and this can drop to as low as 0.6 cu. inch as needed to keep the evaporator pressure above the freezing point or at the pressure to produce the desired outlet air temperature. Compressor displacement is adjusted by changing the pressure inside the crank/piston chamber using a pressure or electronically controlled valve. ● **SEE FIGURE 3–6.**

VANE COMPRESSORS

CONSTRUCTION The vanes of these compressors are mounted in a rotor that runs inside a round, eccentric, or a somewhat elliptical, chamber. The vanes slide in and out of the rotor as their outer end follows the shape of the chamber. Compressors with a round, eccentric chamber have one

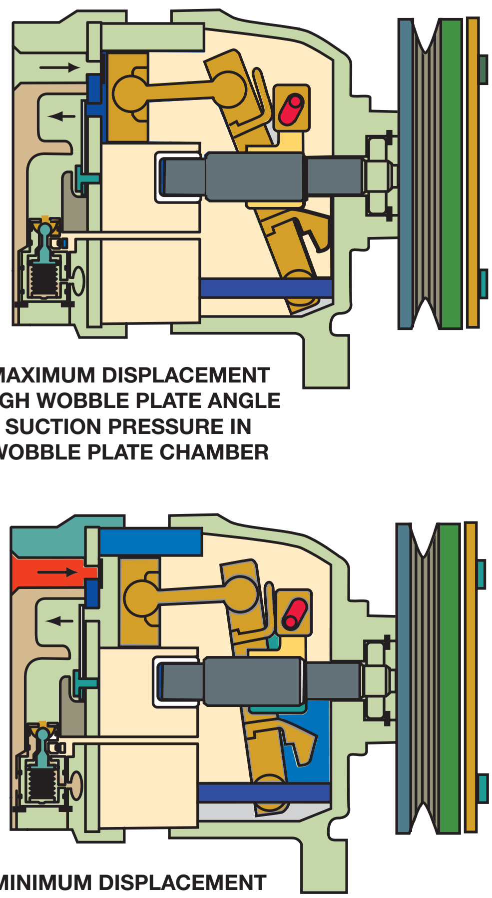


FIGURE 3–5 A variable displacement compressor can change the angle of the wobble plate and piston stroke. This angle is changed by a control valve that senses evaporator pressure, which in turn changes wobble chamber pressure.

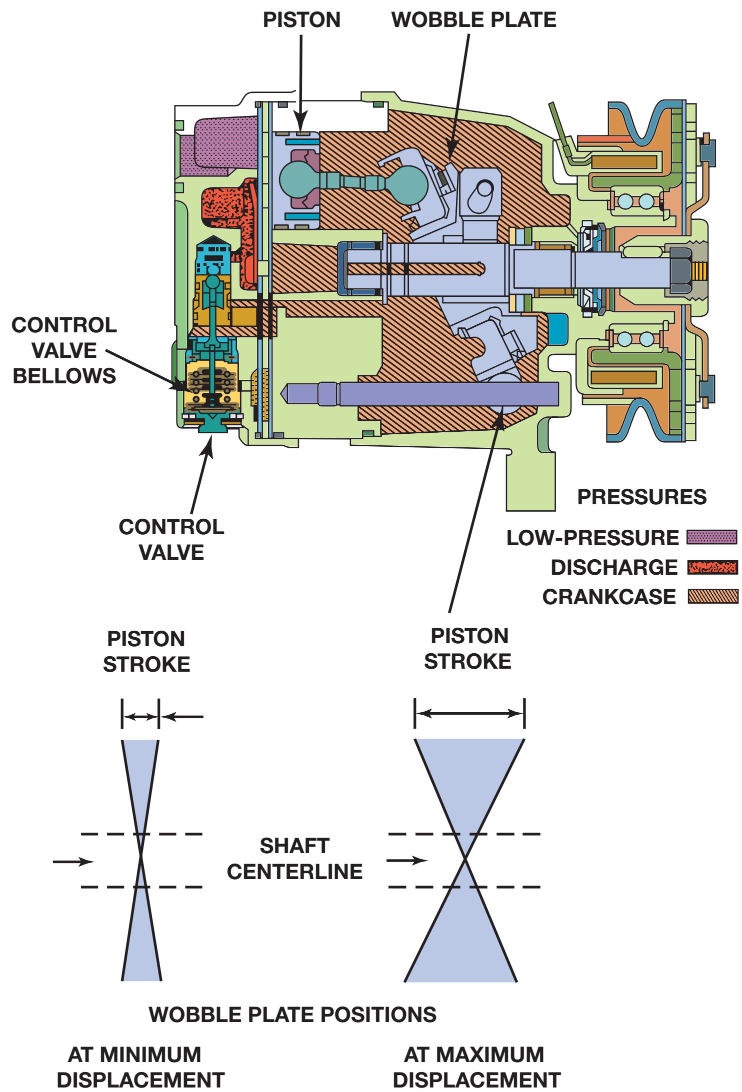


FIGURE 3–6 When the evaporator cools and low-side pressure drops, the piston stroke of a variable displacement compressor is reduced so that compressor output matches the cooling load.

pumping action per vane per revolution. Compressors with an elliptical housing have two pumping actions per vane per revolution. This type of compressor is sometimes called *balanced* because there is a pressure chamber on each side of the rotor.

OPERATION As the rotor turns, in one or two areas, the chamber behind the vane increases in size. This area has a port connected to the suction cavity. The following vane traps the refrigerant and forms a chamber as it passes by the suction port. The trapped refrigerant is carried around to the discharge port. In this location, the chamber size gets smaller which increases the gas pressure and forces it into the high side. Vane compressors have the advantage of being very compact and vibration free. ● **SEE FIGURE 3–7.**

SCROLL COMPRESSORS

CONSTRUCTION Scroll compressors use two major components:

1. **Fixed scroll**—The fixed scroll is attached to the compressor housing.
2. **Movable scroll**—The movable scroll is mounted over an eccentric bushing and counterweight on the crankshaft. It does not rotate, but it moves in an orbit relative to the stationary scroll and as a result is also called an *orbiting piston compressor*.

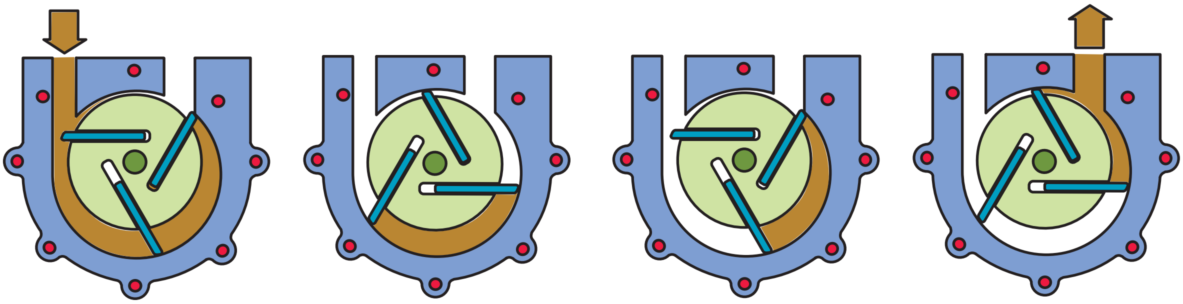


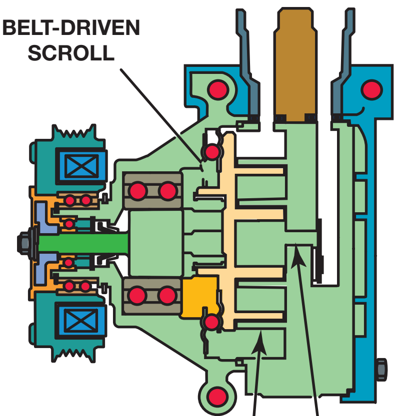
FIGURE 3–7 As the rotor turns in a counterclockwise direction, the vanes move in and out to follow the contour of the housing. This action forms chambers that get larger at the suction ports and smaller at the discharge ports. Evaporator pressure fills the chambers as they get larger, and the reducing size forces the refrigerant into the high side.

Both scrolls have a spiral shape that forms one side of the pumping chamber.

OPERATION As the scroll orbits, it forms a pumping chamber that is open at the outer end. This chamber is moved to the center by the scroll's action as the pressure is increased. Two or three chambers are present at the same time. The outer ends of the scrolls are open to the suction port, and the inner ends connect to the discharge port. ● **SEE FIGURE 3–8.**

ADVANTAGES A scroll compressor has the advantage of having very smooth operation and low-engagement torque that allows the use of a small clutch. A scroll compressor can also be driven at higher revolutions per minute (RPM) than other designs, so that a smaller drive pulley is used. This compressor design is also much more efficient than the other compressor styles when it is operated at the design speed, which is an advantage for vehicles that tend to run most of the time at cruising speed.

DISADVANTAGES The one disadvantage of a scroll compressor is that it is more expensive to manufacture and therefore costs more than a piston-type compressor.



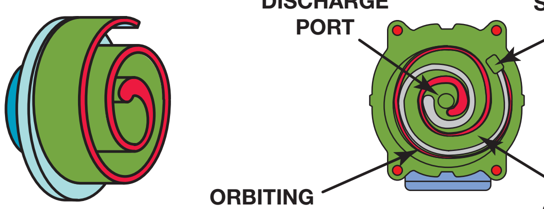


FIGURE 3–8 As the orbital scroll moves, it forms pumping chambers/gas pockets that start at the suction port and forces the refrigerant to the discharge port at the center.

COMPRESSOR CLUTCHES

PURPOSE AND FUNCTION Electromagnetic clutches allow the compressor to be turned on and off. The clutch uses a coil of wire where a magnetic field is generated when electrical current flows through it. The magnetic field pulls the drive plate against the rotating pulley to drive the compressor.

PARTS AND OPERATION Magnetic clutches include:

1. The clutch coil and pulley are both mounted on an extension from the front of the compressor housing. The pulley and its bearing are mounted on an extension of the front head. This placement allows the side load of the drive belt to be absorbed by the pulley bearing and compressor housing. It also allows easier servicing of individual clutch parts.

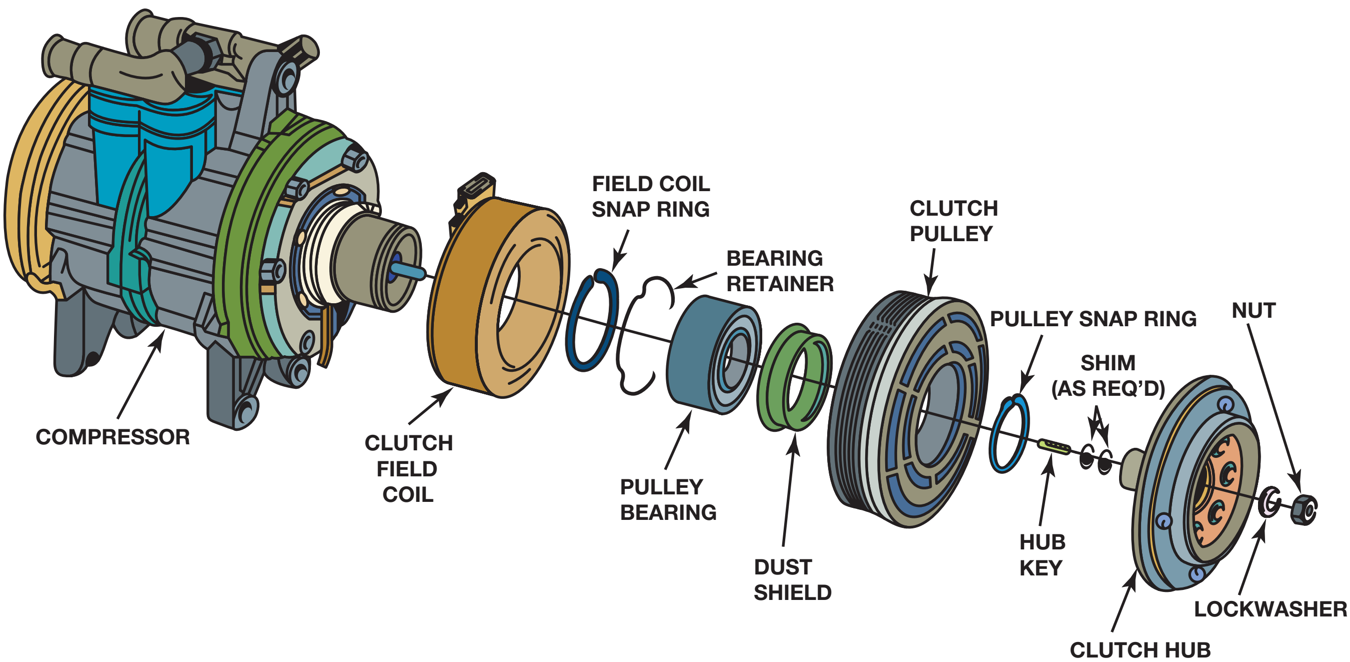


FIGURE 3–9 The electromagnetic clutch assembly includes the clutch field coil, where the magnetic field is created; the clutch pulley, which rides on the pulley bearing; and the clutch hub, which is attached to the input shaft of the compressor. The small shims are added or deleted as needed to adjust the air gap between the clutch hub and the clutch pulley.

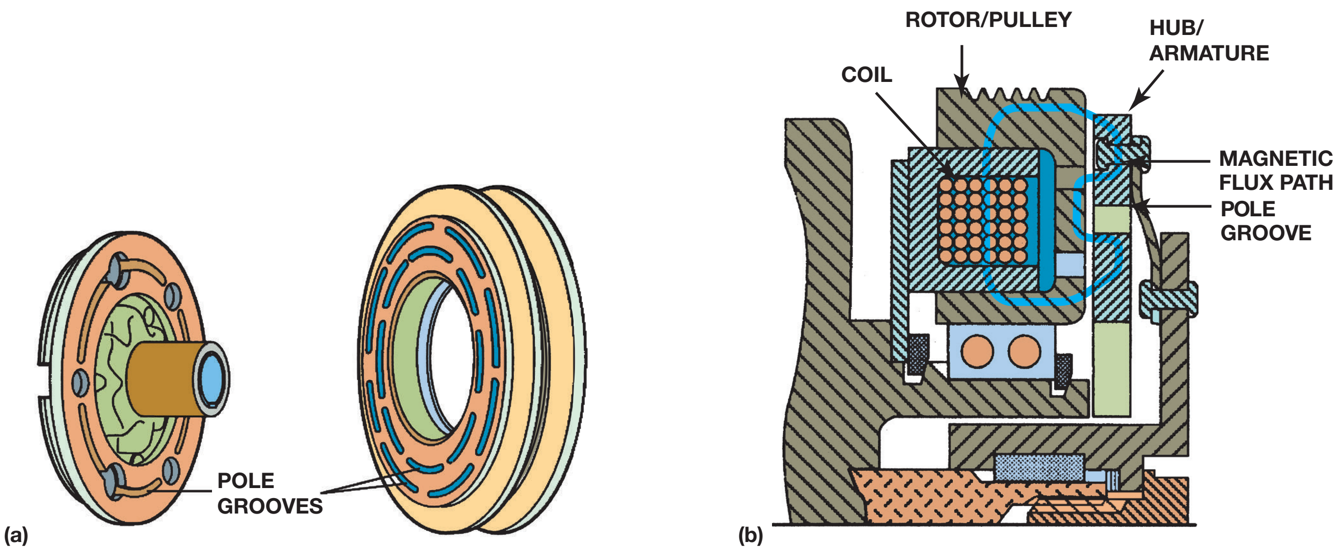
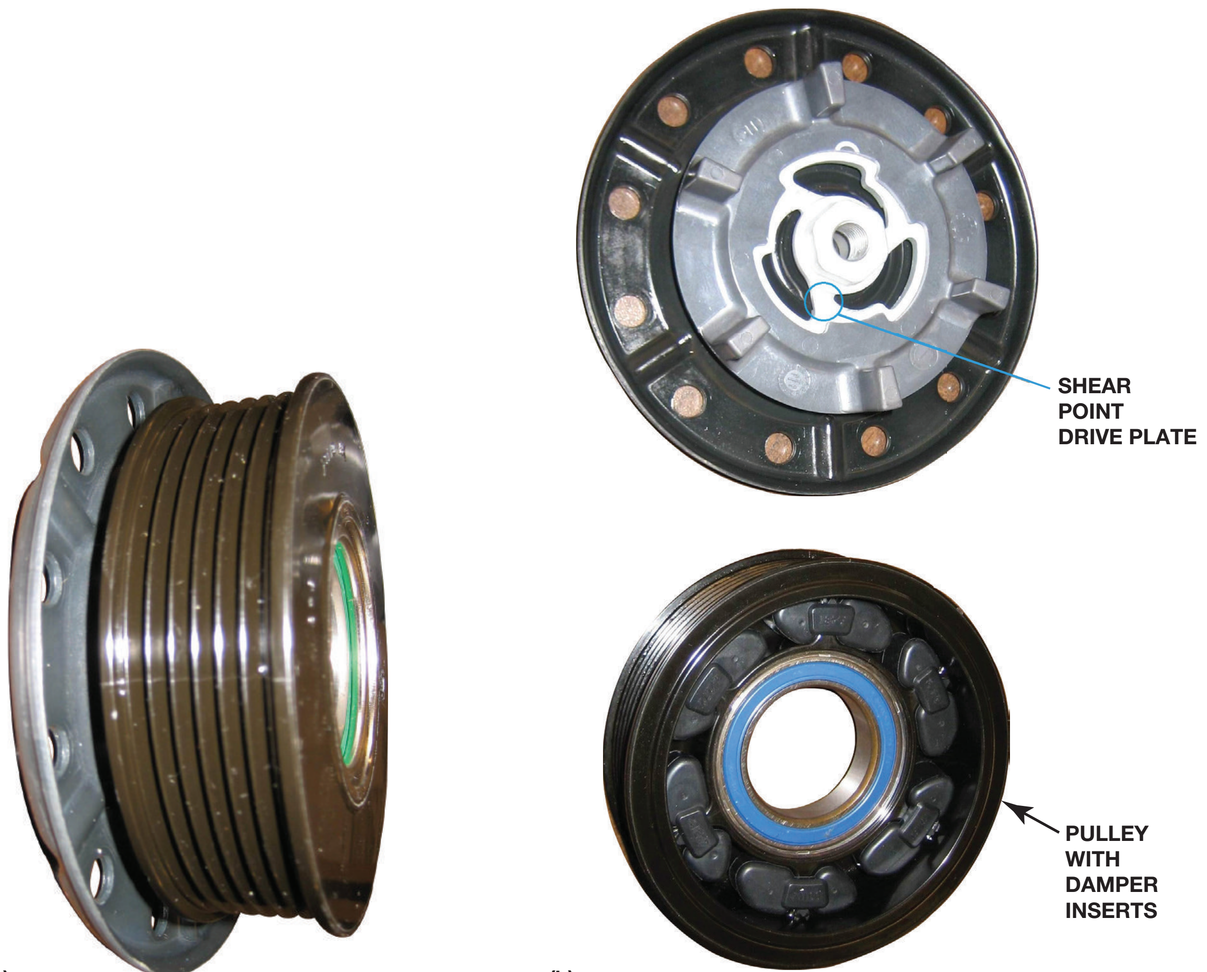


FIGURE 3–10 The magnetic flux path is from the coil and through the metal of the rotor and clutch hub. When it meets a pole groove, it travels from the hub to the rotor or vice versa, which increases the clutch holding power.

2. The **drive plate** is attached to the compressor shaft. The drive plate is also called an *a clutch pulley,* and the pulley is also called a *rotor*. ● **SEE FIGURE 3–9.**

Some design factors used to increase holding power include the following:

- The number of *flux poles*, which are the slots in the face of the clutch armature (the greater the number of slots, the stronger the magnetic hold). ● **SEE FIGURE 3–10.**
- The diameter of the rotor and armature (the larger the diameter, the greater the holding power).
- The use of copper or aluminum in the clutch coil winding (copper produces about 20% greater torque capacity).
- The current draw of the coil (the lower the resistance of the coil, the greater the current draw and the stronger the magnetic field that is created).



(a) (b)

FIGURE 3–11 (a) This damper drive is a one-piece pulley and hub. (b) Torque is transferred from the pulley through the rubber damper inserts (bottom), and the drive plate uses torque-limiting fingers that will shear if the compressor should seize (top).

DAMPER DRIVES Many recent vehicles use a clutchless **damper drive**, electronic-controlled, variable displacement compressor. The pulley always drives the compressor through a rubber portion that dampens rotating engine pulsations.

One variable displacement compressor that uses a damper drive is electronically controlled to go to minimum displacement of 2% output when A/C is not used. This displacement requires very little power and is enough to circulate oil through the moving parts. The pulley drive plate includes a metal or rubber shear portion that can break to protect the drive belt in case the compressor should fail and lock up. ● **SEE FIGURE 3–11.**

Damper drives cannot be cycled for evaporator temperature control. The compressor displacement control valve responds to electrical signals from the control module, and this controls evaporator temperature to deliver the desired outlet temperature and prevent evaporator freeze-up. ● **SEE FIGURE 3–12.**

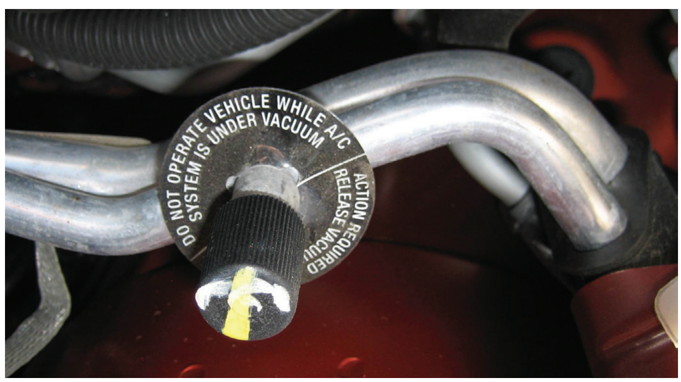


FIGURE 3–12 This tag on the service port indicates a damper-drive compressor that can be damaged if the engine is run without refrigerant in the system.

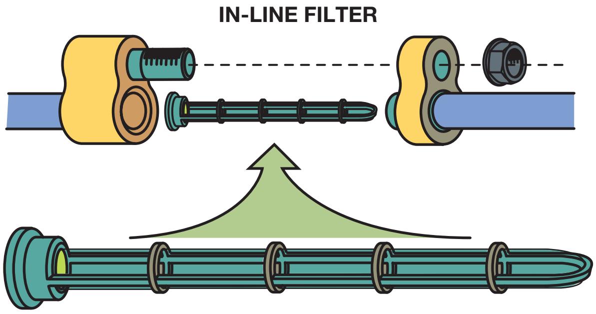


FIGURE 3–13 This filter, about the size of an orifice tube, is installed in the liquid line by the vehicle manufacturer.

COMPRESSOR LUBRICATION

NEED FOR LUBRICATION Refrigerant oil serves several purposes, including the following:

- It lubricates the moving parts of the compressor to reduce friction and prevents wear.
- Refrigerant oil also helps *seal* the compressor shaft seal, the insides of the hoses, and various connections between the parts to reduce refrigerant leakage.
- In addition, it lubricates the TXV and coats the metal parts inside the system to reduce corrosion.

HOW OIL IS CIRCULATED With R-12, oil was miscible (could be mixed) in the refrigerant and the refrigerant carried the oil. The refrigerant oil used in R-134a system does not mix with the refrigerant but instead moves through the system simply with the movement of the refrigerant. If the system has the proper refrigerant charge and the proper amount of oil in the system, then the compressor is lubricated. A loss of refrigerant will also mean a loss of lubricating oil and subsequent compressor failure.

FILTERS AND MUFFLERS

PURPOSE AND FUNCTION **Inline filters** are available from aftermarket sources for installation in the liquid line between the condenser and the OT or TXV and are designed to filter the refrigerant to stop debris from plugging the expansion device.

General Motors is installing inline filters, called a *refrigerant or expansion valve filter*, in the liquid line on selected models. This filter is about the same size and shape as an orifice tube, installed in a connector in the liquid line, and is secured by a joint or reduced/dimpled line section. ● **SEE FIGURE 3–13.**

Mufflers are installed in the discharge or suction line of some systems. These mufflers are usually a simple baffled cylinder and are used to dampen the pumping noise of the compressor. ● **SEE FIGURE 3–14.**

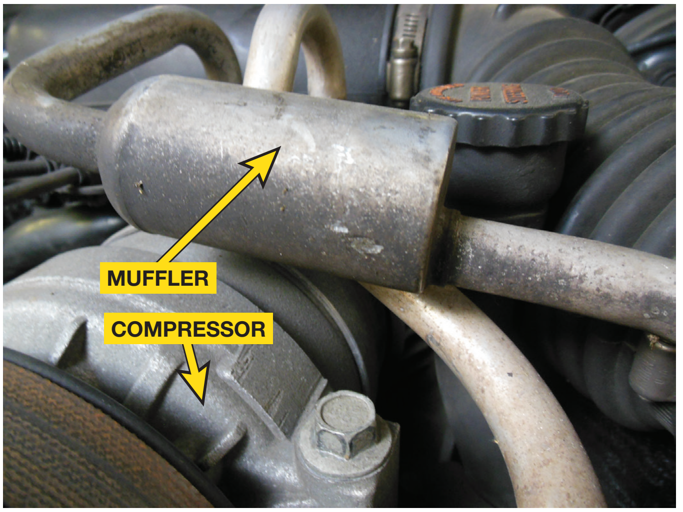


FIGURE 3–14 A muffler is a simple expansion or pulsation chamber with baffles inside the unit to help smooth compressor pressure pulses.

COMPRESSOR VALVES AND SWITCHES

PRESSURE RELIEF VALVES Excessive high-side pressure can produce compressor damage and a potential safety hazard if the system should rupture. Compressors are controlled and protected with several different types of pressure relief valves. Many early systems contain a *high-pressure relief* or *release valve,* or release valve which was mounted on the compressor or at some location in the high side.

- R-12 relief valves are set to release pressure at 440 PSI to 550 PSI (3,000 kPa to 3,800 kPa).
- R-134a valves are a little higher at 500 PSI to 600 PSI (3,450 kPa to 4,130 kPa).
- A relief valve is spring-loaded so excessive pressure will open the valve, and as soon as the excess pressure is released, the valve will reclose. ● **SEE FIGURE 3–15.**

NOTE: Newer systems are designed to release the clutch and shut the system off if pressures get too high to avoid venting refrigerant into the atmosphere.

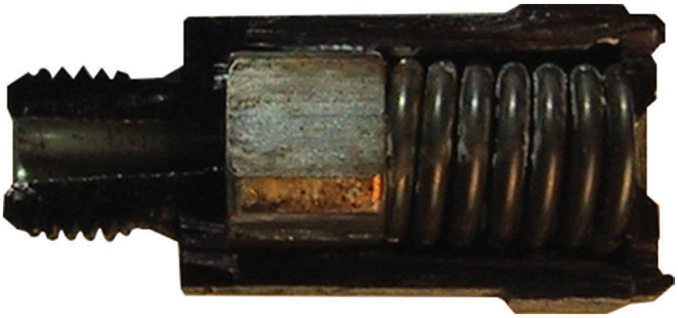


FIGURE 3–15 A high-pressure relief valve contains a strong spring that keeps the valve closed unless high-side pressure (from the left) forces it open. The valve then closes when the pressure drops.

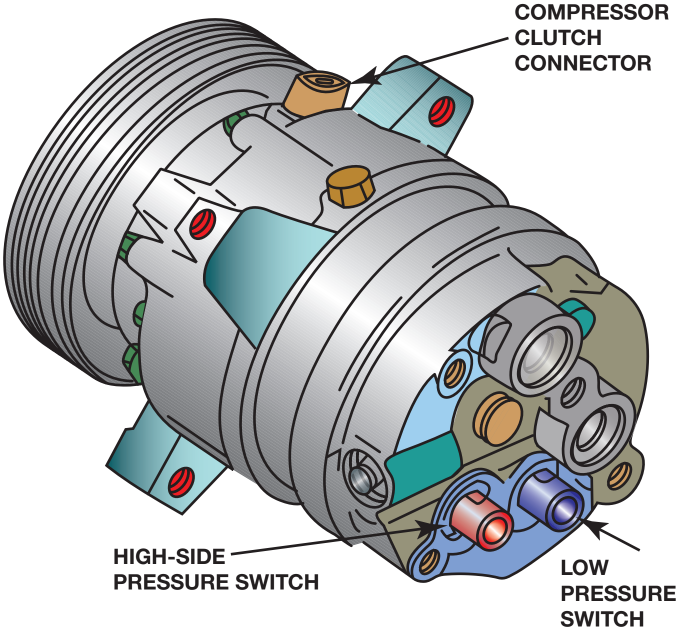


FIGURE 3–16 Check service information for the exact purpose and function of each of the switches located on the compressor because they can vary according to make, model, and year of manufacture of vehicle and can also vary as to what compressor is used.

SWITCHES ON THE COMPRESSOR Many compressors contain one or more of the following:

- A low-pressure switch
- A high-pressure switch
- A low- and/or high-pressure sensor

Switches can be connected to ports, leading to either the suction or discharge cavities in the compressor. These switches are usually used in circuits either to protect the compressor or system from damage or as sensors for the engine control module. ● **SEE FIGURE 3–16.**

COMPRESSOR CONTROL SWITCHES Various electrical switches are used in A/C systems to prevent evaporator icing, protect the compressor, and control fan motors. Control switches can be located anywhere in the system, including at the following positions:

- Compressor discharge
- Compressor suction cavities
- Receiver–drier
- Accumulator ● **SEE FIGURE 3–17.**

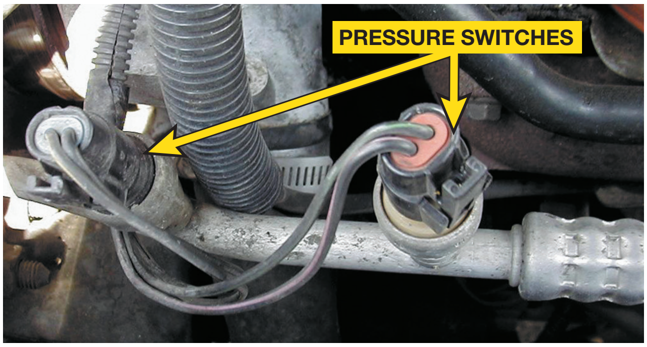


FIGURE 3–17 Typical air-conditioning pressure switches. Check service information to determine the purpose and function of each switch for the vehicle being inspected.

COMPRESSOR SPEED SENSOR Some vehicles use an A/C compressor speed (RPM) sensor so the ECM will know if the compressor is running, and by comparing the compressor and engine speed signals, the ECM can determine if the compressor clutch is slipping excessively. This system is often called a *belt lock* or *belt protection system.* It prevents a locked-up compressor from destroying the engine drive belt, which, in turn, can cause engine overheating or loss of power steering. If the ECM detects an excessive speed difference for more than a few seconds, it will turn the compressor off. Check service information for the vehicle being serviced to determine if the compressor has a speed (RPM) sensor and if so, where it is located and how to check it for proper operation.

A/C COMPRESSOR DIAGNOSIS AND SERVICE

COMPRESSOR CLUTCH DIAGNOSIS A faulty compressor or compressor clutch is indicated if the following conditions are observed:

- The high- and low-side pressures are too close, within 50 PSI (345 kPa).

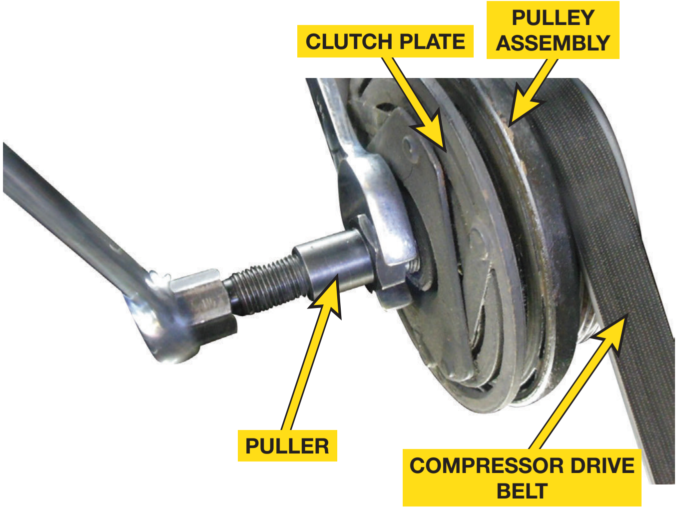


FIGURE 3–18 After removing the retaining nut from the A/C compressor shaft, a special puller is used to remove the compressor clutch plate (hub).

- It cannot produce a high-side pressure of 350 PSI (2,400 kPa) or greater. This test usually requires disconnecting the fan(s) or blocking condenser airflow.
- There is visible damage to the compressor, clutch, or pulley.
- The compressor shaft rotates freely with no resistance.
- Shaft rotation is rough or harsh.
- There is free play when shaft rotation is reversed.
- The clutch has too much or too little air gap.
- The clutch does not apply or release.
- The pulley rotation is rough or with too much free play.

COMPRESSOR CLUTCH REPLACEMENT Most A/C compressor clutches are three-part assemblies with a separate drive hub (armature), rotor pulley, and coil. To remove a clutch assembly, check service information for the exact procedure to follow. Most specified procedures include the following steps:

STEP 1 Remove the locknut or bolt from the compressor shaft. A clutch hub wrench is often required to keep the hub from turning. Some compressors do not use a locknut.

STEP 2 Use the correct tool to pull the hub from the compressor shaft. **SEE FIGURE 3–18.**

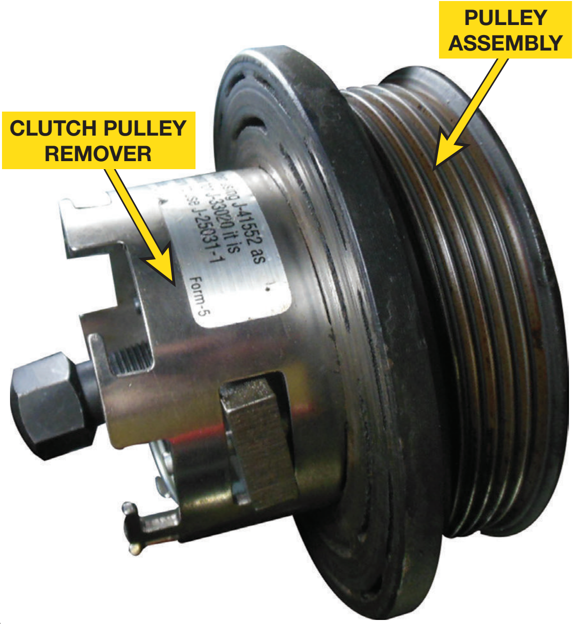
STEP 3 A special puller is required on most compressors but the rotor pulley can be slid off some compressors, such as the Nippondenso compressors. **SEE FIGURE 3–19.**

To reinstall a clutch assembly, perform the following steps:

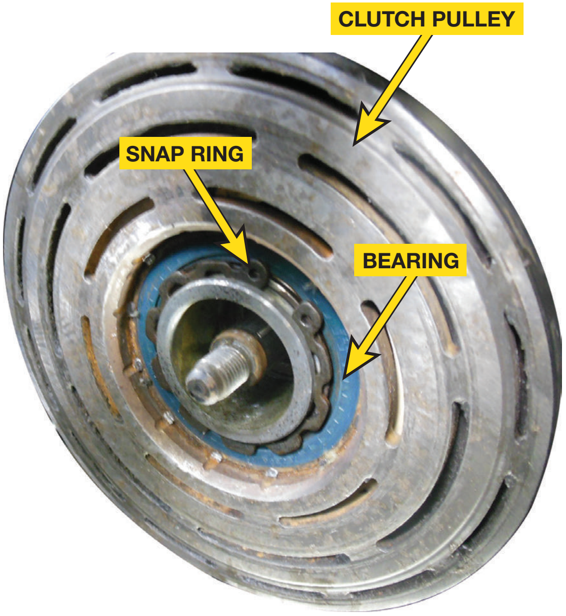
STEP 1 Install the coil, making sure that the anti-rotation pins and holes are aligned and the wire connector is in the correct position. The coil must be pressed in place on some compressors.

STEP 2 Install the coil retaining ring.

STEP 3 Install the rotor pulley and replace the retainer ring. Some retainer rings have a beveled face and this side must face away from the pulley. Test this installation by rotating the rotor pulley and it must rotate freely, with no interference.



(a)



(b)

FIGURE 3–19 (a) The pulley assembly is removed using a special puller on this Dodge truck. (b) The pulley assembly includes the bearing which may or may not be a replaceable part, depending on the compressor.

FIGURE 3–20 Air gap of the clutch is adjusted on some A/C compressors by using thin metal washers called shims. Adding a shim increases the gap and deleting a shim decreases the gap.

STEP 4 On some compressors, install the adjusting shims onto the shaft, install the drive key, and align and install the hub. ● **SEE FIGURE 3–20.**

On many GM compressors, the hub must be pulled onto the shaft. It should be pulled on just far enough to get the correct air gap. ● **SEE FIGURE 3–21.**

STEP 5 If used, install the shaft locknut or bolt and tighten it to the correct torque.

STEP 6 Check the clutch air gap at three locations around the clutch. The clearance should be within specifications at all three points. If it is too wide or too narrow, readjust the air gap. If it is too wide at one point and too narrow at another, replace the hub.

COMPRESSOR SHAFT SEAL REPLACEMENT Every compressor has a seal that keeps refrigerant from escaping through the opening where the pulley driveshaft enters. ● **SEE FIGURE 3–22.**

Many compressors use a rotating **seal cartridge** attached to the shaft and a stationary **seal seat** attached to the front of the compressor housing. The compressor has one or two flats on the shaft so that the seal cartridge is positively driven.

A gasket or rubber O-ring is used so that the seal seat makes a gas-tight seal at the housing, and the seat has an extremely smooth sealing face. The carbon-material sealing member is spring loaded so that its smooth face makes tight contact with the seal seat. The cartridge also uses a rubber O-ring or molded rubber unit to seal the carbon to the driveshaft. Another important part of the seal is the compressor oil,

FIGURE 3–21 On some compressors, the air gap is adjusted by pressing the plate to the correct position.

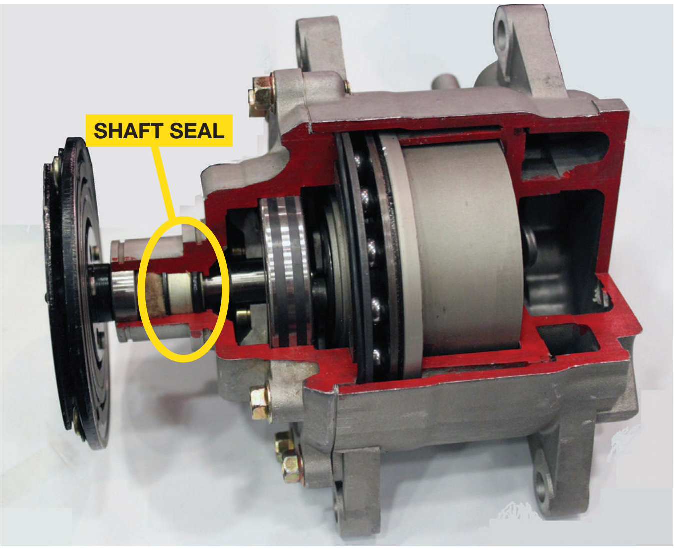


FIGURE 3–22 The shaft seal must keep refrigerant from escaping out the front of the compressor. Most compressors have an oil flow routed to them to reduce wear and improve the sealing action.

which lubricates the surfaces and forms the final seal between the sealing surfaces. ● **SEE FIGURE 3–23.**

A ceramic material has replaced cast iron for the seal seat in some compressors. Ceramic is not affected by water or acids, which can cause rust, corrosion, or etching of the iron seats. Ceramic seats are easy to identify because they are white instead of gray.

Recent compressor designs use a **lip seal**. The lip of the seal is made from Teflon and rides against a perfectly smooth portion of the driveshaft. Some shaft seals use double seating lips. The outer shell of the seal fits into a recess in the compressor housing and is sealed using a rubber O-ring. Gas pressure in the compressor ensures a tight fit between the seal lip and the shaft. ● **SEE FIGURE 3–24.**

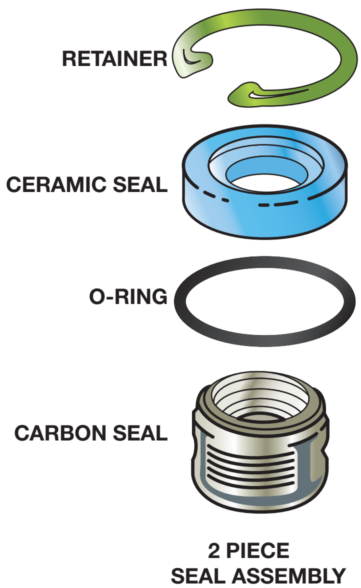


FIGURE 3–23 Many compressors use a two-piece seal with a rotating carbon seal and a stationary seal.

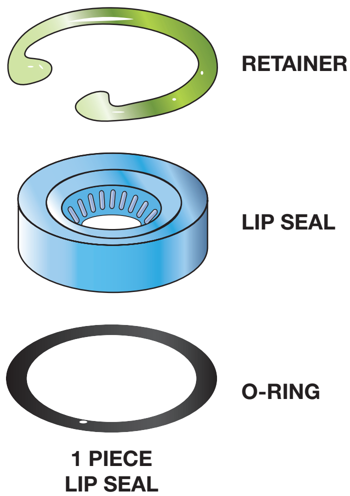


FIGURE 3–24 Some newer compressors use a stationary lip seal that seals against the rotating shaft.

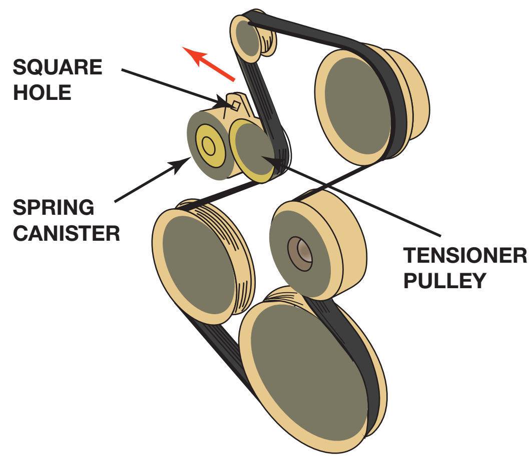


FIGURE 3–25 Moving the automatic tensioner outward allows the serpentine belt to be removed from the pulleys.

TECH TIP

Quick and Easy Belt Noise Test

With the engine running at idle speed, use a spray bottle and squirt some water on the belt and listen for a noise change. If the noise increases, there is a belt tension problem. If the noise decreases but then returns, there is a belt alignment problem.

With most compressors, the shaft seal is removed from the front of the compressor after the clutch plate has been removed. Seals should not be reused and new seal parts should always be installed. Special tools are required for most seal replacements. These tools are designed to grip the seal cartridge or seat so they can be quickly pulled out or slid back into the proper position. Always follow the specified procedure found in service information.

COMPRESSOR DRIVE BELT SERVICE Engine drive belts should be checked periodically for damage and proper tension. If a belt shows excessive wear, severe glazing, rubber breakdown, or frayed cords, it should be replaced. The automatic tensioner on some vehicles includes a belt stretch indicator. If belt stretch of more than 1% is indicated, the belt should be replaced.

Belt slippage is caused by either a worn tensioner or worn belt. A belt that is too tight causes an excessively high load on the bearings of the components driven by the belt. Traditionally, belt tension is checked by pushing the center of the belt inward and then pulling it outward while noticing how much the belt is able to be deflected. Most manufacturers use a total movement of 0.5 inch as a maximum distance. Most manufacturers recommend using a belt tension gauge that is hooked onto the belt and uses a scale to show tension.

To remove and replace a drive belt using an automatic tensioner, perform the following steps:

STEP 1 Note the routing of the belt as per the under hood decal or in-service information.

STEP 2 Relieve the belt tensioner and slip the belt off the pulleys. A wrench can be used for this procedure on most tensioners. ● **SEE FIGURE 3–25.**

STEP 3 Remove the belt, and with the belt off, spin the pulleys to make sure that they are clean, not worn, and rotate freely.

FREQUENTLY ASKED QUESTION

What Is a Stretch Belt?

Starting in 2007, some vehicles use a stretch-fit, multi-rib belt without a tensioner. The elastic nature of the belt allows it to be stretched to install it over the pulleys, and the stretch provides the tension to keep it from slipping. A special tool or strap is required to install a stretch belt, and some manufacturers advise to cut the belt to remove it. ● **SEE FIGURE 3–26.**

To replace the belt, perform the following steps:

STEP 1 Cut the old belt to remove it.

STEP 2 Place the special installation tool into position on the second pulley. Start the belt onto the pulley.

STEP 3 Rotate the engine by hand far enough so the pulley rotates and pulls the belt into position and then remove the special tool. ● **SEE FIGURE 3–27.**

If the special installation tool is not available and the pulley has holes through it, follow these steps:

STEP 1 Install the belt onto the pulley, and secure it to the pulley using a zip tie.

STEP 2 Rotate the engine by hand far enough so the pulley rotates and pulls the belt into position.

STEP 3 Cut the zip tie. ● **SEE FIGURE 3–28.**

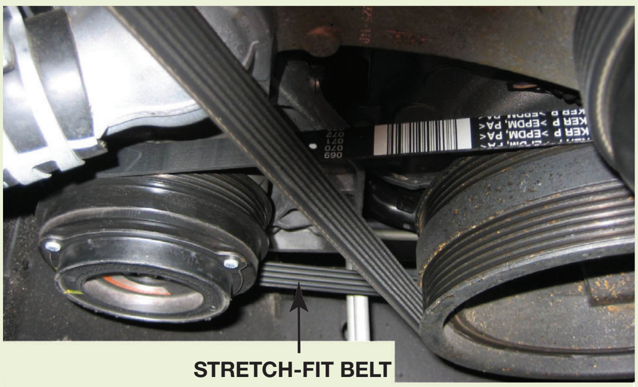


FIGURE 3–26 A stretch-fit belt is identified by the lack of an idler or method of adjusting belt tension.

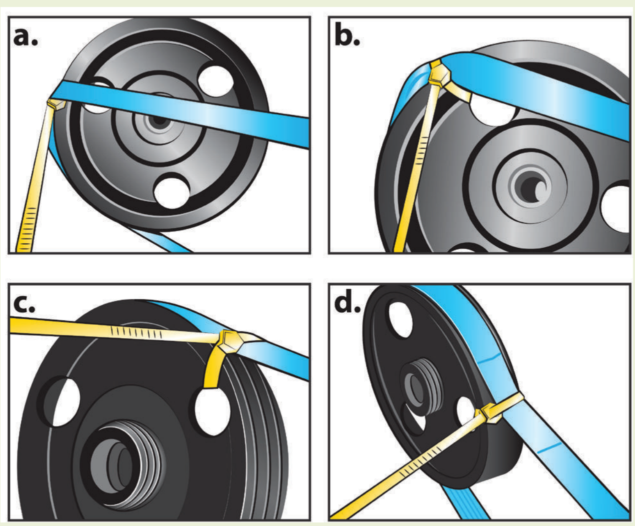


FIGURE 3–28 If a special installation tool is not available and the pulley has holes, then a tie wrap can be used to install a new stretch belt.

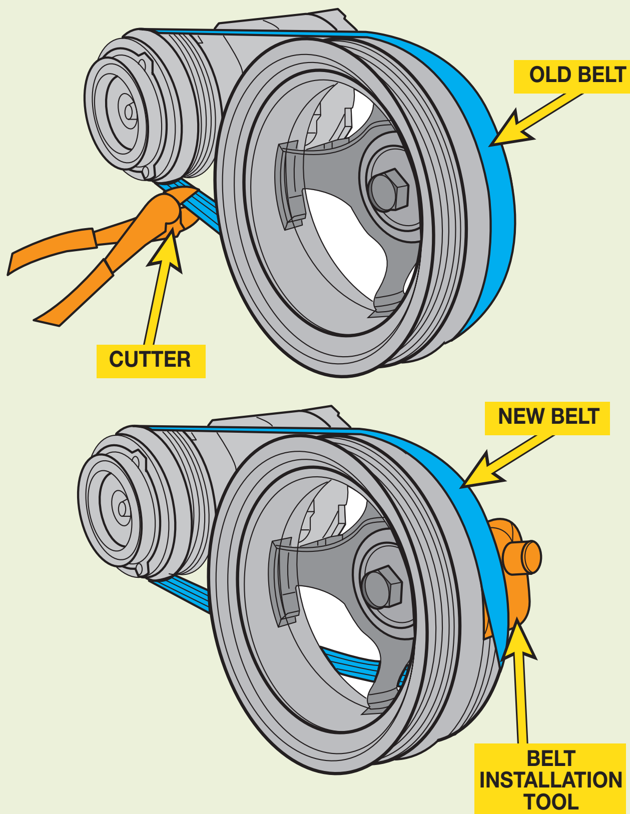


FIGURE 3–27 The old stretch belt is removed by cutting it and the new one installed using a belt installation tool.

STEP 4 Install the belt on some pulleys, rotate the tensioner, slide the belt into the proper position, and release the tensioner.

STEP 5 Check to ensure proper belt placement on each pulley.

Start the engine and check for proper belt operation.

BELT TENSIONER SERVICE The tensioner is designed to keep the belt tight enough so it does not slip but not so tight that the belt or bearings in the driven components will fail early. It must also dampen the tensioner arm to stop excess motion/bouncing and align the pulley to the belt. Tensioners can fail, and at least one source recommends installing a new tensioner when the belt is replaced.

To check belt tensioner operation, perform the following steps:

STEP 1 With the engine running at idle speed, observe any tensioner movement, and there should be a rather gentle motion. If it appears to bounce back and forth a large amount, the dampener portion is probably worn out.

STEP 2 Stop the engine and move the tensioner through its travel. It should move smoothly against the spring pressure with no catches or free portions.

STEP 3 With the pulley unloaded, check for free play or rough bearing operation. Next, spin the bearing and it should rotate smoothly for two or three revolutions. Also, check for excess arm motion at the pivot bushing.

REPLACEMENT COMPRESSORS

IDENTIFY THE UNIT Replacement compressors are available as new or rebuilt units, and proper identification is made from the vehicle make, model, and engine size. Then, if needed, proper identification is made by the old compressor make and model. At times, a failed compressor is replaced with a different compressor make and model if the mounting points, clutch diameter and belt position, and line fittings are the same. ● **SEE FIGURE 3–29.**

OIL CHARGE Having the proper amount of oil in the system during compressor replacement is an important factor. Too much oil in a system can reduce system performance, and too little oil can cause early compressor failure. Many compressors are equipped with *shipping oil* that is not intended for long-term lubrication. Be sure to read the information that usually comes with the new compressor and follow the directions. Most manufacturers recommend draining all the oil from the old compressor and measuring the amount drained. ● **SEE FIGURE 3–30.**

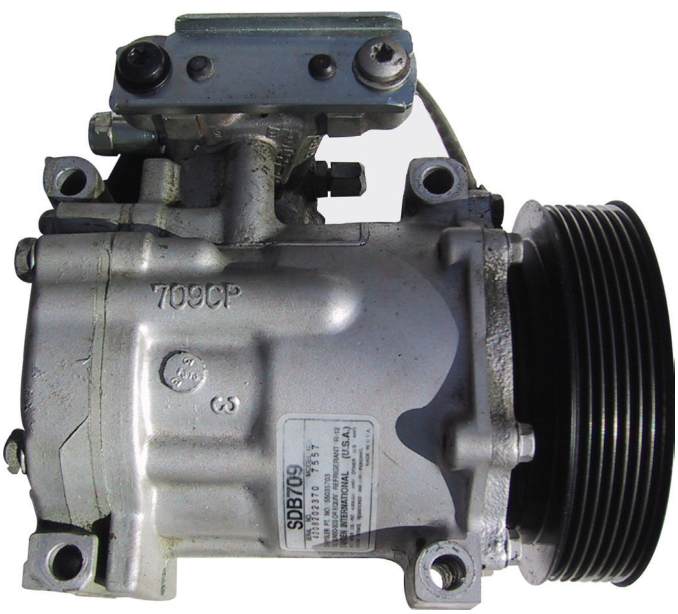


FIGURE 3–29 The decal on this compressor identifies the type (SDB709) and the serial number. Note also that it uses a seven-groove, multi-V clutch, four mounting bolts, and vertical-pad service ports at the side.

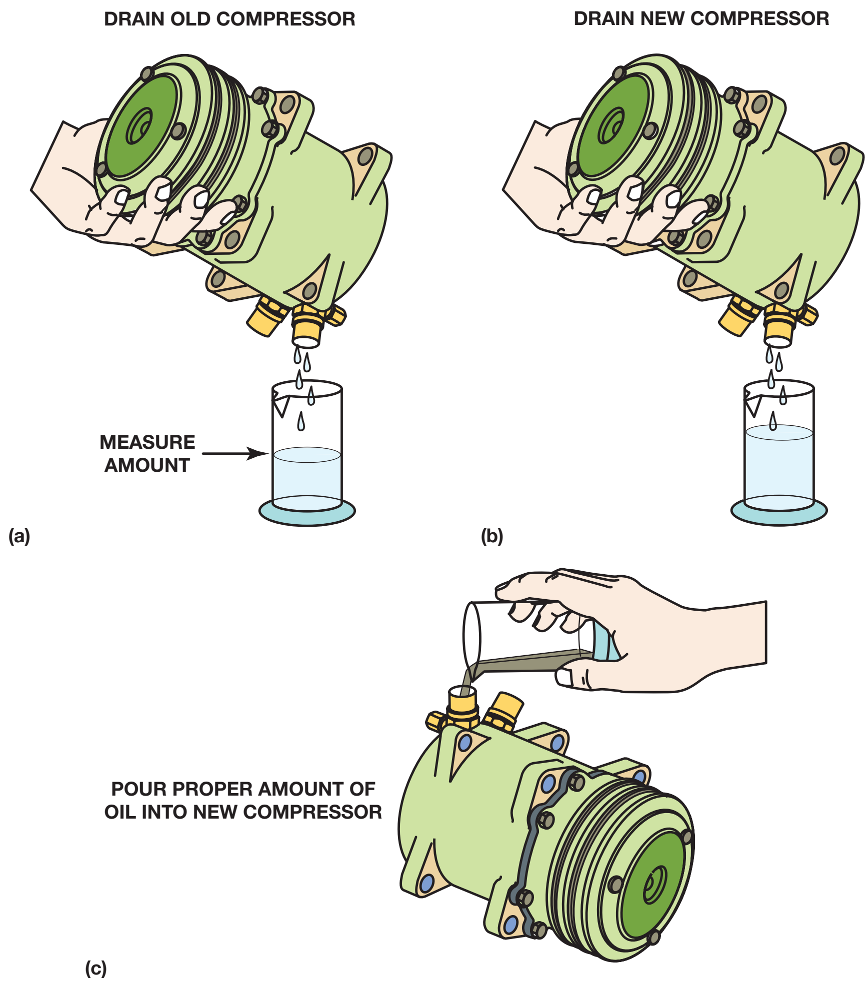


FIGURE 3–30 (a) The oil should be drained from the old compressor (top left); rotate the compressor shaft and the compressor to help the draining. (b) Drain the oil from the new compressor (top right). (c) Pour the same amount of oil drained from the old compressor or the amount specified by the compressor manufacturer of the proper oil into the new compressor (lower).

If the amount is within certain limits, such as 3 oz. to 5 oz., the same amount of new oil is then added to the new compressor. Always follow the manufacturer's recommendations or processes. A typical example includes:

- If the amount drained was below 3 oz., then 3 oz. of new oil is added.
- If the amount drained is more than 5 oz., then 5 oz. of new oil is added.

Replacing a compressor usually includes the following steps:

STEP 1 Adjust the oil level in the compressor as instructed by the vehicle or compressor manufacturer.

STEP 2 Install the compressor on the engine and replace the mounting bolts.

STEP 3 Install the drive belt, adjust the belt tension, and tighten all mounting bolts to the correct torque.

STEP 4 Using new gaskets or O-rings, connect the discharge and suction lines. Then evacuate, charge, and check for leaks at all fittings.

SUMMARY

1. Various compressor types and models are used with vehicle A/C systems.
2. Compressor models can use a variety of clutch and pulley designs.
3. Some variable displacement compressors use a damper pulley in place of a clutch.
4. Compressors are lubricated by oil that is circulated by the refrigerant.